RESIDENTIAL ENERGY EFFICIENCY: TURKISH CASE

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ABSTRACT

RESIDENTIAL ENERGY EFFICIENCY: TURKISH CASE

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This study aims to analyze residential electricity demand of Turkey between 2008 and 2015, provide relative efficiency scores of provinces in electricity use and reveal the determinants of (in)efficiency through stochastic frontier approach. Empirical results indicate that having higher income, inhabiting in densely populated provinces and living at detached houses result in increasing electricity consumption at the residential sector. On the other hand, as household size increases, electricity consumption per capita decreases. The findings also point out that Turkish households do not use electricity for the purpose of heating and cooling in general. Nonetheless, prosperous provinces use electricity for cooling at high temperatures. Based on the estimated efficiency scores, 8-year mean energy efficiency of Turkey is found to be approximately 0.83. This suggests that on average Turkey could have used 17% less electricity to produce the same amount of energy services between 2008 and 2015. In other words, Turkish households have an average electricity saving potential of 17% in the study period. The results of the inefficiency effects equation suggest that being well-educated of women and being married have a positive impact on improving residential efficiency. On the other hand, provinces located in the coastal area and those with higher loss-illegal electricity use rates are more inefficient in electricity use.

Furthermore, the findings of the study imply that inefficient use of electricity at the residential sector has not declined over time. This can be evaluated such that the efficiency policies implemented by the authorities after 2007 did not have a significant impact on improving efficiency in residential electricity use. Since our study is the first one that analyzes electricity consumption and efficiency at the provincial level based on frontier analysis, it can shed light on the consecutive studies of regional development and energy efficiency.

Keywords: Residential, Efficiency in Electricity Use, Stochastic Frontier Analysis, Turkey

ÖZ

KONUTTA ENERJİ ETKİNLİĞİ: TÜRKİYE ÖRNEĞİ

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Bu çalışmada, stokastik sınır analizi yöntemi ile Türkiye konut sektörüne ilişkin elektrik talebinin 2008-2015 yılları için analiz edilmesi, illerin konutta elektrik tüketimlerine ilişkin etkinlik düzeylerinin belirlenmesi ve bu etkinlik düzeylerinin işaret ettiği etkinsizliğin nedenlerinin ortaya koyulması hedeflenmiştir. Ampirik sonuçlar, gelir düzeyi ile nüfus yoğunluğu artışının ve müstakil konutlarda yaşamanın elektrik tüketimi artışına neden olduğunu göstermektedir. Öte yandan, hanehalkı büyüklüğü arttıkça konutta kişi başına elektrik tüketimi azalmaktadır. Sonuçlar, genel olarak Türkiye'de ısınma ve soğutma amacı ile konutlarda elektrik kullanılmadığını gösterse de, gelir düzeyi yüksek illerin soğutma amaçlı elektrik tüketimine yönelmekte olduğu görülmektedir. Tahmin edilen etkinlik rakamlarına göre, ülkenin 8 yıllık etkinlik ortalaması yaklaşık 0,83'tür. Bu rakam, 2008-2015 döneminde Türkiye'de konutlarda aynı çıktıyı elde edebilmek için %17 daha az elektrik kullanılabileceğini göstermektedir. Bir başka deyişle, söz konusu zaman aralığında hanehalkları, elektrik tüketiminde yaklaşık %17 düzeyinde bir tasarruf potansiyeline sahiptir. Diğer taraftan, etkinsizliğin nedenlerini de açıklamayı amaçlayan çalışma sonuçlarına göre, kadınların eğitim düzeyi ile evli çift sayısının artması bir ilde elektrik tüketiminde etkinliğin artmasına katkı sağlamaktadır. Öte yandan, deniz kıyısında konumlanmış iller ile kayıp-kaçak elektrik tüketiminin fazla olduğu illerde elektrik kullanımının daha etkinsiz olduğu sonucuna varılmıştır. Ayrıca, illerin konutta etkinsiz elektrik kullanımlarında zamanla bir iyileşmenin olmadığı görülmektedir. Bu durum, özellikle 2007 sonrasında birçok sektör için benimsenen etkinlik politikalarının, konutta istenilen sonuca ulaşamadığına işaret etmektedir. Bu çalışma, il bazında sınır analizi yöntemi ile konutta elektrik tüketimini ve etkinliğini inceleyen ilk çalışma olması yönüyle, bundan sonra yapılacak bölgesel gelişme ve enerji etkinliği çalışmalarına ışık tutabilecek niteliktedir.

Anahtar Kelimeler: Konut, Elektrik Kullanımında Etkinlik, Stokastik Sınır Analizi, Türkiye

To my family

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CHAPTER 1

INTRODUCTION

Electricity is undoubtedly one of the greatest innovations of humankind. It has now become a part of our daily life and a life without electricity cannot be imagined. Even a blackout that will be experienced for a few hours can impair many activities at different sectors and has social and economic costs beyond imagination. Thus, abundant and uninterrupted supply of electricity has a vital importance especially for those countries aiming sustainable economic and social growth.

According to International Energy Agency (IEA, 2019), global electricity demand rose by 4% in 2018 compared to 2017. This increase in electricity demand was nearly twice as fast as total energy demand, and it was the fastest pace since 2010. IEA also states that 45% of global electricity demand in 2018 was met by renewables and nuclear power. On the other hand, coal and gas-fired power plants contributed extensively to electricity generation. The share of coal and gas fired power plants in global electricity generation in 2018 are 38% and 23%, respectively, and emissions from the power generation constitutes 38% of total energy-related CO_2 emissions. At this point, satisfying increasing electricity demand by existing scarce resources without contradicting greenhouse gas emissions targets poses a great challenge.

Electricity consumption in Turkey also has an increasing trend over time. Parallel to its economic growth, industrialization and increasing population, Turkey's electricity consumption has increased dramatically over time. According to Turkish Statistical Institute (TurkStat) data, total electricity consumption in 2017 has increased by 60% since 2007. In electricity generation, natural gas and coal have received the highest shares in 2017 with 37% and 33%, respectively. On the other hand, in the same year industrial and residual sectors have contributed to electricity consumption by 47% and 22%, respectively.

While dealing with increasing electricity demand, Turkey also has to struggle with serious problems related to the supply side. One of these problems is that being the main source of electricity production, there is a high level of foreign dependence in natural gas amounting to 99% in 2017 (Energy Market Regulatory Authority [EMRA], 2018b). Moreover, most of the natural gas has been supplied from certain countries for years. Turkey's dependency on these countries is a great threat for security of supply considering a possibility of a diplomatic crisis that might undergo.

Other than foreign dependence in natural gas, increasing greenhouse gas emissions related to energy sector is another challenge for Turkey. TurkStat (2019) reveals that the overall greenhouse gas emissions as CO_2-eq for Turkey in 2017 are 526.3 million tonnes and energy sector has the largest share of emissions with 72.2%. In per capita terms, CO_2-eq emissions grew from 4 tonnes in 1990 to 6.6 tonnes in 2017. Furthermore, total greenhouse gas emissions as CO_2-eq have increased by 140.1% from 1990 to 2017. This striking increase in greenhouse gas emissions forces Turkey to revise its energy policies. For the solution of this problem, renewable energy sources may be the first option that comes to mind. Nonetheless, electricity production from these resources is heavily dependent on climate conditions, which affects abundant and uninterrupted supply of electricity adversely.

Although the conventional definition of energy efficiency is to use less energy in order to provide the same service, it could offer to countries more than this. The efficiency policies adopted by countries play an important role in sustaining economic growth, reducing emissions and ensuring energy supply of security in the easiest and cheapest way. Molina (2014), by analyzing costs and cost effectiveness of energy efficiency programs for the USA over the period 2009-2012, concludes that energy efficiency is the lowest-cost resource compared to different electricity generation options such as building a new power plant. Furthermore, according to IEA (n.d.) the world would use

12% more energy in 2016 if energy efficiency improvements had not been realized since 2000. This amount of savings corresponds to the total energy requirement of the European Union.

Similar to other countries, Turkey has also taken important steps in promoting energy efficiency in the recent years. Having considerably high energy consumption per capita and energy intensity, Turkey initiated energy efficiency measures mainly by the enactment of Energy Efficiency Law No. 5627 in 2007. Since then, many other legislations have succeeded this law, in which important goals like encouraging efficiency in different sectors such as industry, transportation etc. are set. Other than these sectors, certain regulations targeting directly energy efficiency at dwellings have also been introduced. Therefore, energy efficiency has been crucial from the policy perspective in Turkey.

According to TurkStat (2018), the number of the households has exceeded 22 million in 2017, and the share of residential sector in total electricity use has reached roughly 22%. It means that nearly one fourth of total electricity production is consumed at dwellings. Therefore, it is crucial to analyze consumption patterns of residential sector, which is one of the main electricity consuming sectors, and determine reasons for inefficient electricity use at dwellings. Moreover, revealing the impact of present energy efficiency policies on household electricity consumption will be essential for future policies.

Considering the scarcity of the available studies focusing on efficiency in residential electricity use, the novelty of our study is that we analyze residential energy efficiency and its determinants at the provincial level for Turkey by using a parametric frontier method i.e., Stochastic Frontier Analysis (SFA). One of the objectives of our study is to contribute to the literature by estimating residential electricity demand function of Turkey between 2008-2015 by using the variables reflecting household and dwelling characteristics besides the standard energy demand variables such as income, electricity price and climate. We focus only on electricity as an energy source and particularly 2008-2015 period due to data availability. On the other hand, another aim is to provide relative electricity efficiency scores of provinces in Turkey and reveal the determinants of (in)efficiency. Following the inefficiency effects model proposed by Battese and Coelli (1995), we estimate both residential electricity demand and inefficiency effects equations simultaneously. After obtaining efficiency scores, we categorize provinces into certain groups according to their efficiency levels, and discuss the reasons for being (in)efficient.

The rest of the study is organized as follows. Chapter 2 presents Turkey's electricity outlook by focusing on the trends on electricity consumption and production. After discussing energy related problems it struggles, main legislations on energy efficiency in Turkey are introduced historically.

Chapter 3 reviews the studies measuring efficiency in primary energy use and residential energy use based on input demand functions with SFA. Furthermore, the studies measuring efficiency in residential electricity use based on the same methodology are discussed in detail. After concentrating on the energy efficiency studies on Turkey, the contribution of our study is specified.

Chapter 4 concentrates on methodology. After elaborating the approaches and methods on efficiency measurement, some prominent models based on SFA are examined in detail. Lastly, the model proposed by Filippini and Hunt (2011) is introduced in terms of its econometric specification and main contributions to the efficiency literature.

Chapter 5 introduces our energy demand frontier model and the variables used in the model, and then empirical results of the study are evaluated. The variables accounting for residential electricity demand and affecting (in)efficiency in residential electricity use are determined.

The final part comprises concluding remarks and some policy recommendations.

CHAPTER 2

ELECTRICITY OUTLOOK AND ENERGY EFFICIENCY POLICES IN TURKEY

In this chapter, we will present an overview of electricity sector by concentrating on the trends[1] on electricity consumption[2] and production in Turkey. After considering the problems Turkey has been trying to cope with for years, main legislations on energy efficiency will be discussed in a historical sequence.

2.1 Electricity Overview of Turkey

Parallel to its economic growth, industrialization and increasing population, Turkey's electricity demand has increased dramatically over time. According to the TurkStat data, total electricity consumption that was equal to 155,000 GWh (Gigawatt Hour) in 2007 has reached to 249,000 GWh in 2017 with a 60% increase. After the sharp decrease in 2009 as a result of the global financial crisis, Turkey has continued to experience rising electricity consumption per capita in line with its economic growth as seen in Figure 2.1. Turkey's consumption per capita has increased by 6.4% in 2017 compared to 2016, which signals to policy makers the need for implementing new policies in the forthcoming years to satisfy increasing electricity demand.

[1] In accordance with the scope of our empirical study, we will focus on post-2007 period while discussing these trends.

[2] Other than Figure 2.9, all figures and interpretations on electricity consumption in this Chapter are based on invoice-based electricity consumption.

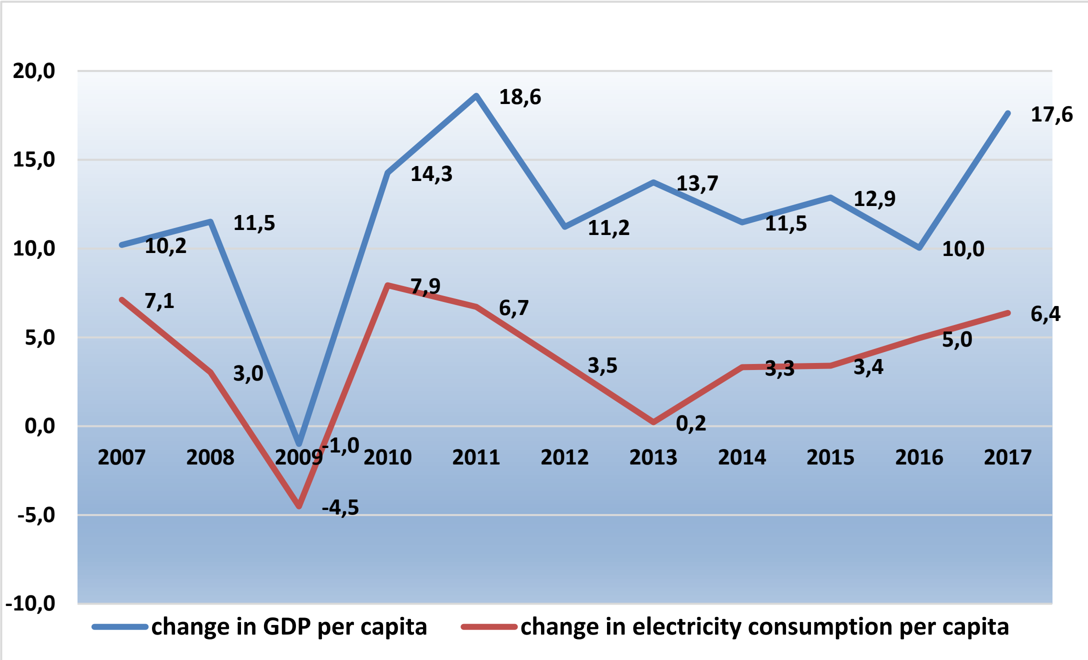

Figure 2.1 Changes in income and electricity consumption per capita over the period 2007-2017 (%)
Source: *TEDC, Electricity Distribution and Consumption Statistics of Turkey, published by TurkStat*

Besides this remarkable increase in consumption, Turkey's electricity generation has also been growing rapidly for decades. Total production that was equal to 191,000 GWh in 2007 has reached to 297,000 GWh in 2017 with a 55% increase (TurkStat). On the other hand, the installed capacity in Turkey has developed drastically from 2007 to 2017, and it has reached 85,200 MW (Megawatt) in 2017 with a 109% increase compared to that in 2007 (Turkish Electricity Transmission Company, n.d.-a).

As it can be observed from Figure 2.2, by the end of 2017, the share of natural gas power plants (including liquid and natural gas power plants) in installed capacity is 32.29%, while the share of hydroelectric power plants and lignite power plants are 24.21% and 11.36%, respectively. On the other hand, the share of renewable energy sources (including hydraulic) within installed capacity is 43.26%, whereas the share of thermal sources is 56.74%.

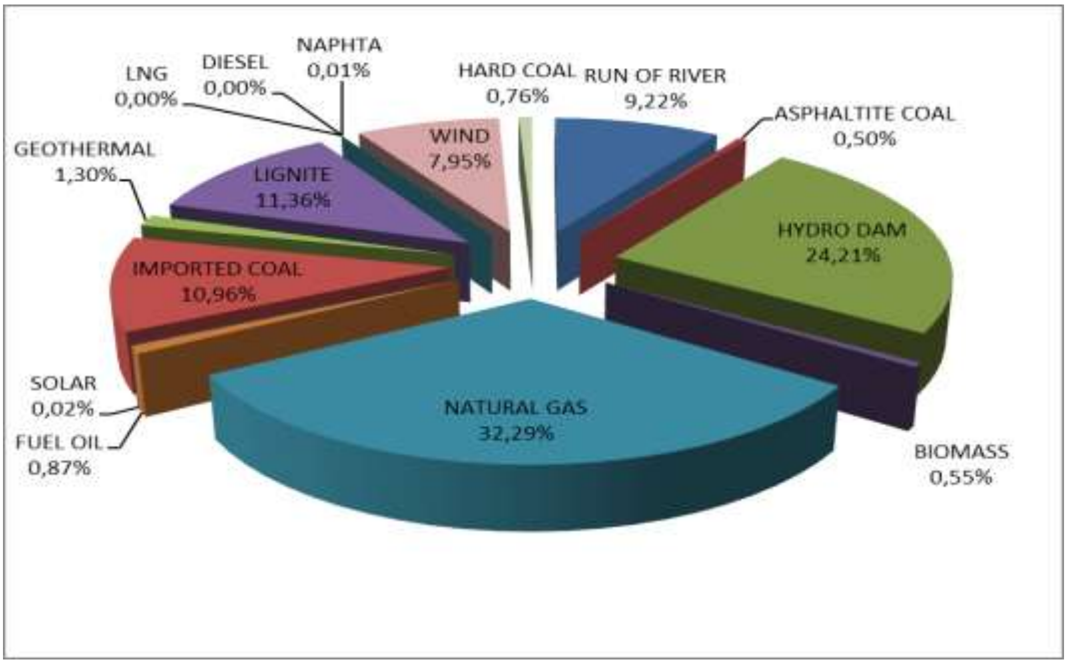

Figure 2.2 Distribution of licensed installed capacity by sources at the end of 2017 (%)
Source: *EMRA (2018a)*

Considering the share of energy sources used in electricity generation over the period 2007-2017 as shown in Figure 2.3, it is clear that there has been an increase in the share of renewable energy resources and wastes in the recent years. Nonetheless, seasonality of hydropower supply and unavailability of old coal plants affect Turkey's struggle of the electricity generation mix adversely. Therefore, Turkey continues to rely mostly on the fossil fuels such as coal and natural gas in production of electricity. Particularly, natural gas, which is the primary imported fossil fuel, is still the main source of electricity production. Even though its share in electricity production decreased remarkably from 2014 to 2016 as a result of rapid increase in renewable energy sources, an increase has been observed again in 2017 as seen from Figure 2.3.

According to the report of IEA (2017), Turkey ranks the ninth and the fifth in 2015 among IEA member countries in terms of the share of the fossil fuels and natural gas in electricity generation, respectively. Turkey occupies the third place behind New Zealand and Italy in terms of geothermal sources in electricity production whereas it ranks the seventh in relation to hydro electricity generation with a record high production in 2015.

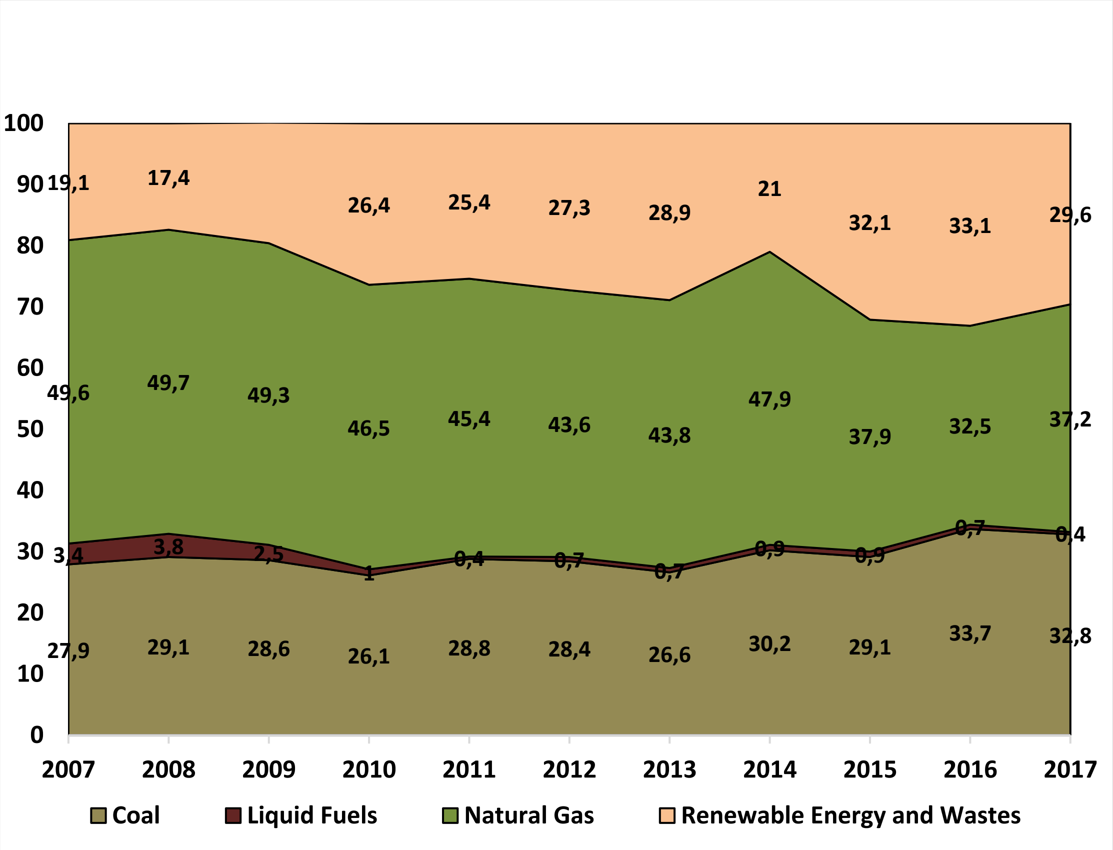

Figure 2.3 Shares of energy resources in electricity generation over the period 2007-2017 (%)
Source: *TETC, Electricity Generation - Transmission Statistics of Turkey, published by TurkStat*

Turkey is an import dependent country, and energy imports have an important share in its total imports. Its energy imports comprise 15.9% of total imports in 2017[3]. As mentioned before, natural gas is the primary energy source in electricity production. Nonetheless, its domestic production is very limited, and almost all of the natural gas used in electricity production is imported. According to EMRA (2018b), only 0.64% of total natural gas supply in 2017 was domestic, and the rest was imported from

[3]Retrieved on May 6, 2019 from Republic of Turkey Ministry of Trade website https://www.ticaret.gov.tr/istatistikler/dis-ticaret-istatistikleri.

different countries. Furthermore, Turkey imported 51.93% of natural gas from Russia, 16.74% from Iran and 11.85% from Azerbaijan in 2017. This indicates that Turkey imports more than 80% of its natural gas from these three countries, and its dependency on these countries has not changed over the years as seen in Figure 2.4. This situation may pose a great threat for security of supply. Therefore, it is another important issue, on which policy makers should work.

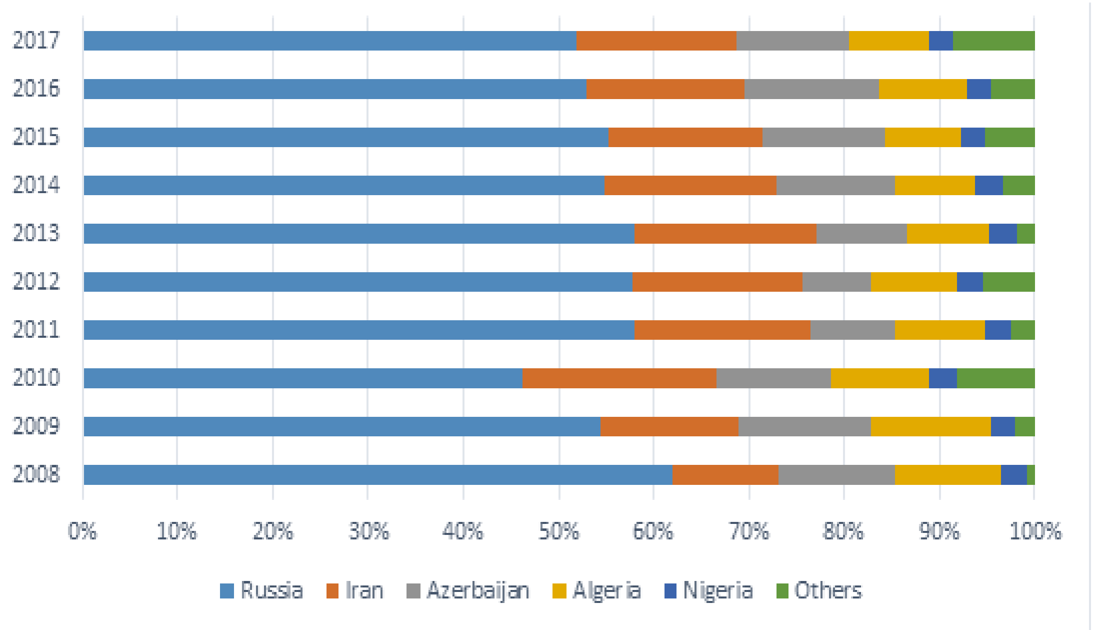

Figure 2.4 Changes in share of source countries for natural gas import over the period 2008-2017
Source*: EMRA, (2018b)*

Reducing its dependence on foreign resources without contradicting its greenhouse gas emission targets is another challenge for Turkey. As seen from Figure 2.5, energy has the largest share in greenhouse gas emissions among different sectors, and its share is approximately 70% between 2007 and 2015. Turkey still relies on coal besides natural gas in electricity generation and, coal, although mainly produced locally, emits more pollutants than other non-renewable resources. At this point, Turkey aims to increase the share of renewable energy sources, to add nuclear power to its energy mix, to reduce its energy import dependency, to maximize use of domestic resources, and to cope with high levels of emissions. Nonetheless, it seems still a difficult task for Turkey to fulfill all these targets synchronously in the near future.

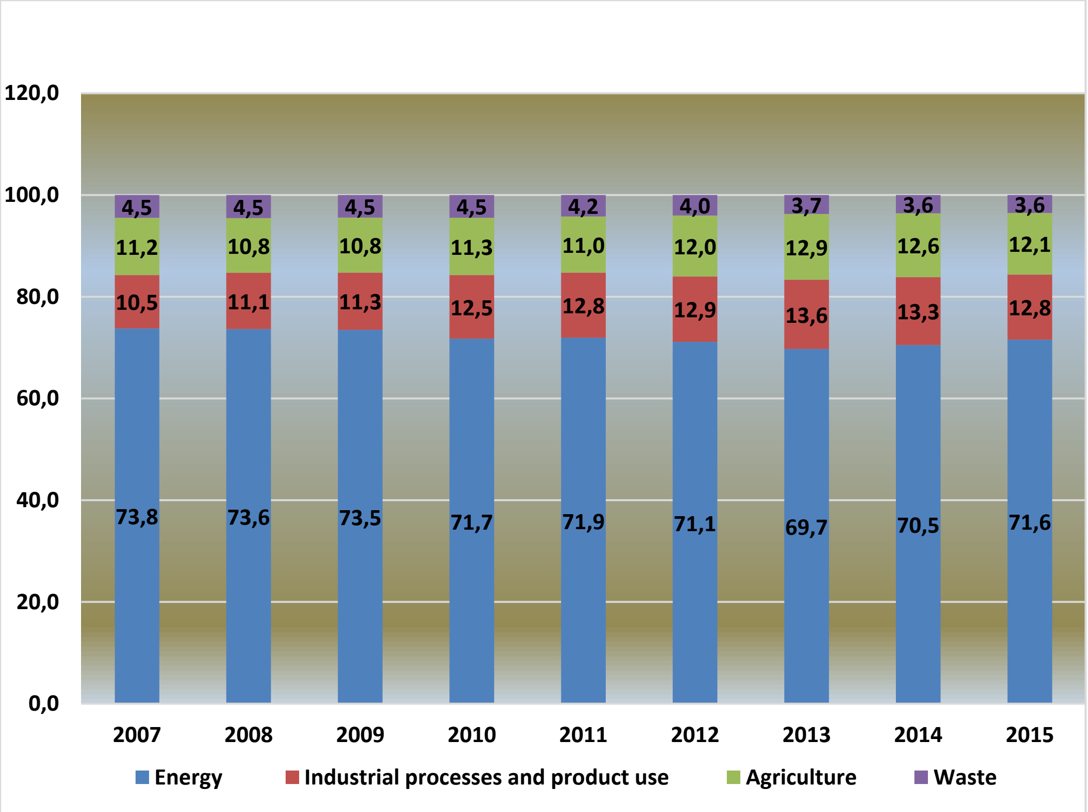

Figure 2.5 Greenhouse gas emissions by sectors (%) over the period 2007- 2015
Source: *TurkStat, Greenhouse Gas Emissions Statistics*

High electricity loss rate has been also one of the important problems in Turkey for years. In 2014, this rate for Turkey was 15.7%, whereas OECD countries and world average were 6.6% and 8.7%, respectively (Turkish Electricity Transmission Company, n.d.-b). This implies that 15.7% of electricity produced and given to the system is lost while being transmitted and distributed due to certain technical and non-technical reasons. Technical losses on the transmission or distribution systems can be reduced by means of additional investments. Transmission losses are usually fixed, and constitute a small portion of all losses in Turkey, which was 2.09% in 2017 (EMRA, 2018a). On the other hand, distribution loss especially due to illegal electricity use is still a crucial problem. Illegal electricity use can be in different forms. Adjusting the electric meter to make electricity use look like less than the real use or installing a line from the power source to the necessary point for by-passing the electric meter are common examples of illegal electricity use (Onat, 2010). Illegal electricity use makes electricity production costly since it affects the distribution quality of electricity and prevents supply of uninterrupted electricity to subscribers. The privatization process of the Turkish electricity distribution completed in 2013, has aimed to avoid distribution losses in electricity system. EMRA has set loss targets for every distribution region since 2011. Besides these targets, some sanctions have started to be imposed on distribution companies that cannot achieve targeted values for their regions. Even though all these policies have been effective in decreasing technical losses by means of new investments at many distribution regions, illegal electricity use has not declined as targeted, especially in the eastern part of Turkey. Loss-illegal use rate in 2017 was realized as 64.82% in Dicle and 53.3% in Vangölü Regions[4] where overall rate was 12.6% for Turkey (EMRA, 2018a). In addition to being a threat to electricity power system, illegal electricity use puts also an economic burden on consumers living in the regions with low rates of loss-illegal use since EMRA applies the same electricity prices to all provinces, and the cost of lost electricity is reflected to the consumers who pay their electricity bills regularly (Onat, 2018).

As mentioned before, total electricity consumption has increased by 60% from 2007 to 2017. When distribution of net electricity consumption in Figure 2.6 is taken account, the industrial sector stands out as the largest final consumer of electricity. On the other hand, the residential sector with a consumption share of nearly one fourth of total electricity production in Turkey has also an important role. This is roughly similar to the residential sector's share in EU countries, which is 25% (Aydın, 2018). Both industrial and residential sectors together account for more than 70% of total consumption. In Akbostancı et.al (2018), residential sector is found to be one of the

[4] Dicle distribution region includes the provinces Diyarbakır, Şanlıurfa, Batman, Mardin, Siirt and Şırnak, while Vangölü distribution region consists of the provinces Bitlis, Hakkari, Muş and Van.

highest energy intensive sectors in Turkish economy, coming second after the public electricity and heat production sector. The study reveals that while energy intensity in the economy declines by 50% from 2001-2012 overall, in residential sector there is a reverse trend. In the period of 2001-2013, a 20% increase is observed in the residential sector's energy intensity.

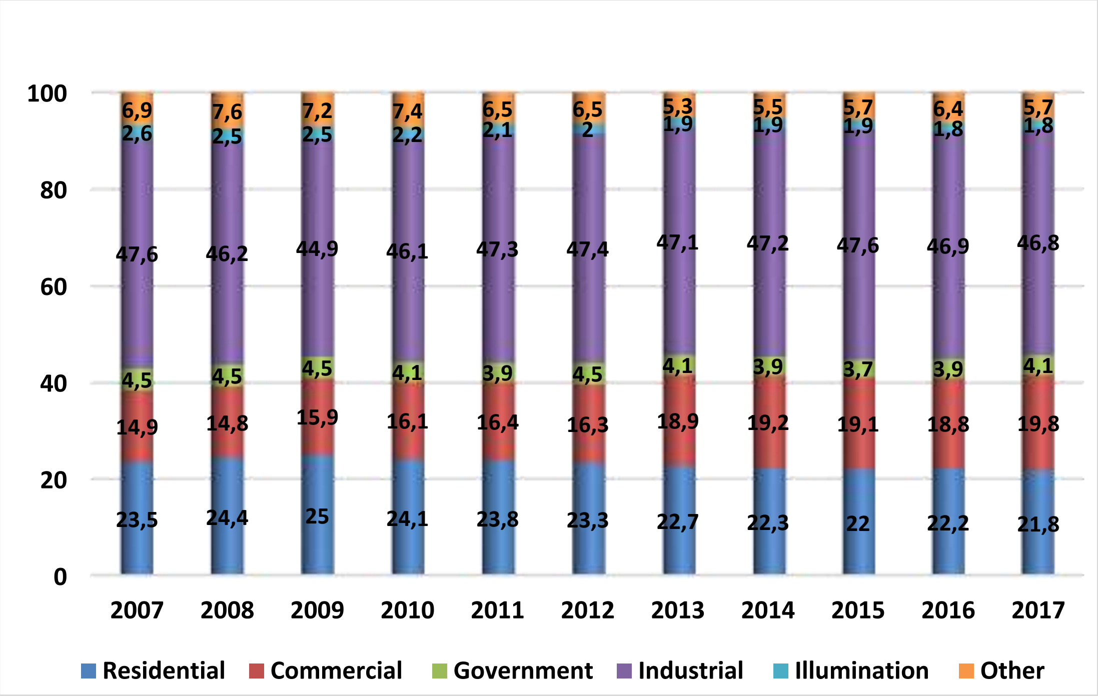

Figure 2.6 Distribution of net electricity consumption by sectors over the period 2007-2017 (%)
Source: *TEDC, Electricity Distribution and Consumption Statistics of Turkey, published by TurkStat*

According to Figure 2.7, electricity consumption per capita in Turkey increases substantially over the period 2007-2017, and residential use contributes to the overall consumption extensively. Furthermore, consumption per capita value for residential sector, which was 517 kWh (Kilowatt Hour) in 2007, has increased by 30% to 671 kWh in 2017. This considerable increase in residential electricity use may be attributed to income growth, urbanization, and the changes in technology and consumption trends.

Rapid increase in the electrical appliances is another important factor that accounts for this increasing trend in residential electricity consumption. Especially ownership of air conditioners, computers, microwave ovens, dishwashers and freezers has grown remarkably between 2002 and 2016. The findings of Aydın (2018) based on Turkish Household Budget Survey 2016 reveal that households' ownership of air conditioners and freezers over the period 2002-2016, has increased from 3% to 19% and 5% to 24%, respectively. The use of these energy intensive appliances is expected to further increase in line with economic growth and their increased affordability.

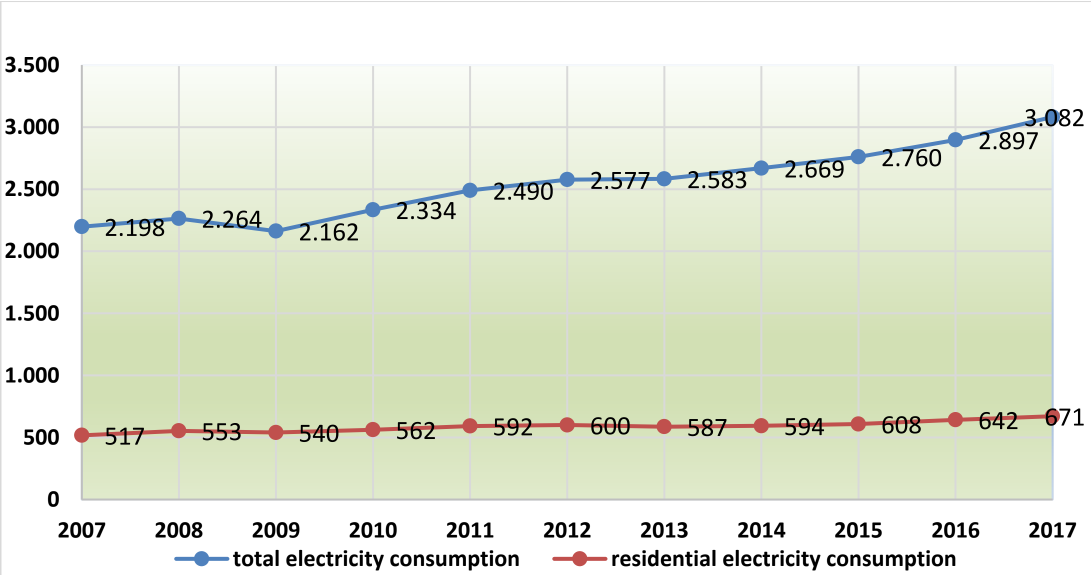

Figure 2.7 Total and residential electricity consumption per capita over the period 2007-2017 (kWh)
Source: *TEDC, Electricity Distribution and Consumption Statistics of Turkey, published by TurkStat*

Province-based residential electricity consumption per capita values in relation to Turkey's average are illustrated in Figure 2.8. It is observed that, Antalya, İzmir, Muğla, Mersin and Adana are the most electricity consuming cities, whereas Şırnak, Hakkari, Mardin, Diyarbakır, Kars and Muş are the least electricity consuming ones per capita.

It is important to consider that these consumptions are invoice-based, and the cities with lower consumptions have remarkably high loss-illegal electricity use rates. To illustrate, the residential electricity consumption per capita of Şırnak in 2015 is 78.6% lower than Turkey's average. Nonetheless, the loss-illegal use rate in this city is already 79.1%, and this indicates that the actual consumption of Şırnak is much more than the value stated. Hence, instead of only invoice-based consumption, considering also amounts of loss-illegal electricity use will enable us to make more accurate analyses and interpretations.

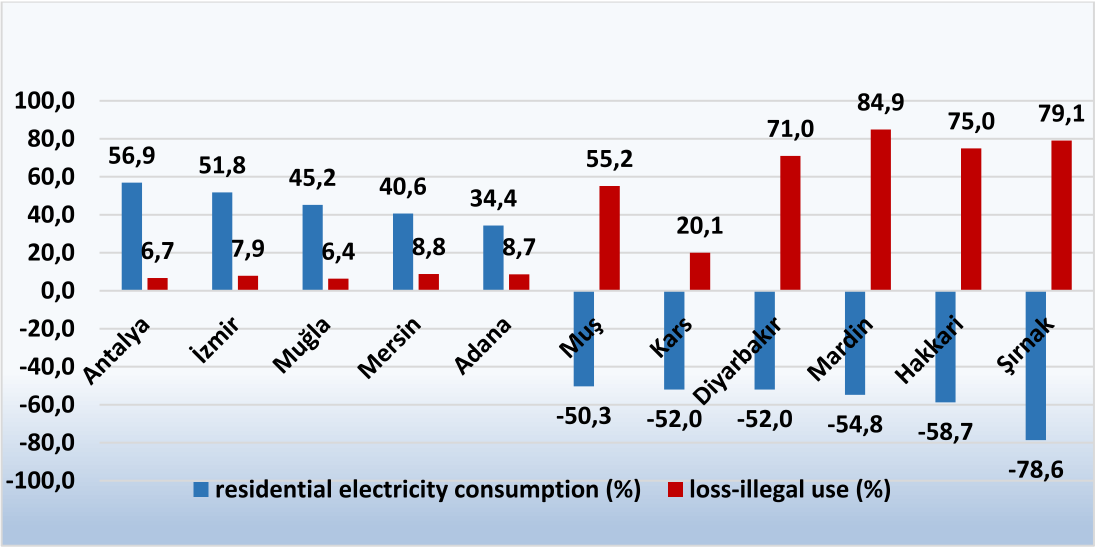

Figure 2.8 Invoice-based residential electricity consumption per capita in relation to Turkey's average and loss-illegal use in 2015 (%)
Source: *TurkStat Regional Statistics on Energy, and TEDC Amounts of Loss-Illegal Electricity Use*

Unlike Figure 2.8, Figure 2.9 takes into account of electricity consumption[5] per capita including loss-illegal use. Accordingly, Mardin, Antalya, Hakkari, Şanlıurfa and Diyarbakır are the most electricity consuming cities while Çankırı, Kars, Kastamonu, Kütahya and Adıyaman are the least electricity consuming ones per capita. To illustrate, the residential electricity consumption per capita of Hakkari in 2015 is 58.8% higher than Turkey's average, and the loss-illegal electricity use rate in this city is 75%.

[5] For further information in obtaining consumption values, see Chapter 5 Empirical Model and Results of this study.

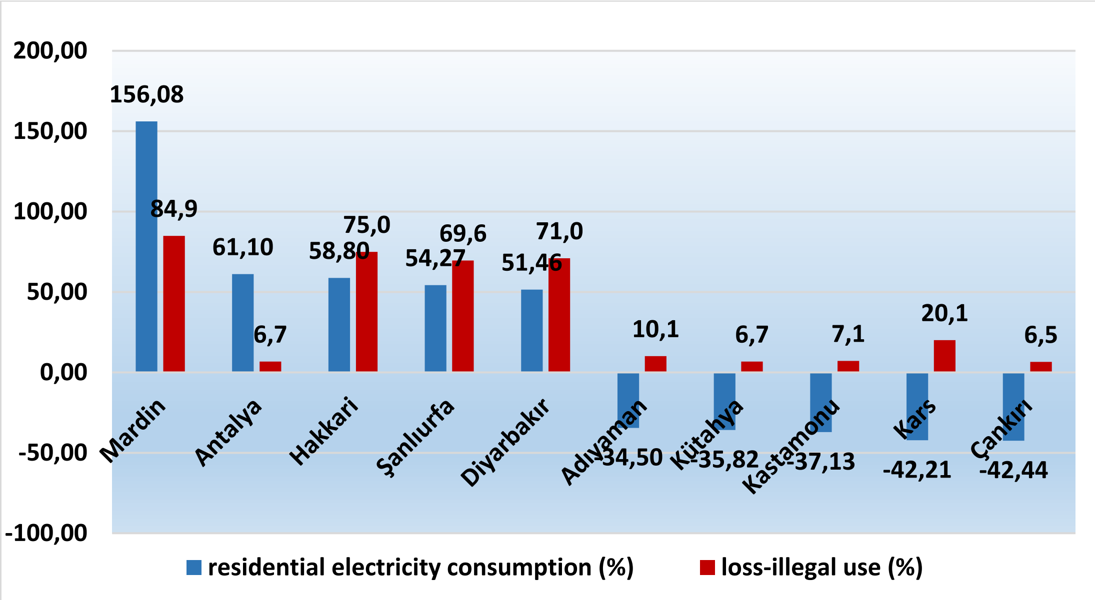

Figure 2.9 Actual residential electricity consumption per capita in relation to Turkey's average and loss-illegal use in 2015 (%)
Source: *TurkStat Regional Statistics on Energy, and TEDC Amounts of Loss-Illegal Electricity Use*

To conclude, Turkey as a developing country still heavily depends on non-renewable resources in electricity production. However, each one of these resources has its own deficiencies. Coal causes air pollution, whereas natural gas supply depends on the foreign sources, which creates the problem of security of supply. One solution to these problems may be to promote renewable resources and increase their share in total installed capacity and electricity production. Nonetheless, renewable energy resources' dependence mostly on climate conditions makes this solution doubtful[6].

[6] Furthermore, increasing share of renewable energy sources in electricity generation brings along one more important problem to the energy markets as discussed in Erbach (2017). Since renewable resources have low or zero marginal cost, the large scale of generation from renewables results in lower market clearing electricity prices in a competitive market[6]. Lower wholesale electricity prices and the lower use of conventional electricity generation plants such as coal and gas affect the profitability of these fuel-based plants adversely. As a result, these power plants have difficulty in covering their fixed costs; even they are confronted with shutting down. To deal with this problem which also endangers system security and security of electricity supply, Turkey as many European countries has put into practice the "Capacity Mechanism" in 2018. The main beneficiaries of this mechanism in Turkey are gas-fired and coal-fired generators. Renewable power plants that benefit from or eligible for feed-in tariffs or benefitted from the feed-in mechanism in the past are excluded. In the scope of this regulation, certain amount of capacity payment is made to these plants by Turkish Electricity Transmission Company mainly to keep them in the system. However, the necessity of this

At this point, energy efficiency comes into stage as a means of reducing consumption of main electricity consuming sectors, especially the residential sector, which consumes almost a quarter of total electricity production.

2.2 Energy Efficiency Policies in Turkey

Energy is undoubtedly one of the most important inputs in every field of life. Thus, abundant and uninterrupted supply of energy is vital to sustain a great number of economic, social and daily activities.

It is projected that worldwide energy demand will at least double by 2050 (World Energy Council, 2013). Considering the difficulty of meeting today's growing energy demand by existing scarce resources, the situation in the future seems uncertain. Therefore, this pessimistic scenario forces countries to take urgent measures on energy efficiency. The conventional definition of energy efficiency is to use less energy in providing the same service. On the other hand, energy efficiency is regarded as not so much a "hidden fuel" but could in fact be our "first fuel" (IEA, 2010).

As a consequence of rising energy prices since the 1970's and the challenges in promoting energy security, the concept of energy efficiency has attracted escalating attention over time. Furthermore, global greenhouse gas emissions have increased the significance of energy efficiency studies all over the world. Similar to the global developments, energy efficiency in Turkey gained importance after the energy crises in the 1970's. After the 1980's Turkey took important steps in promoting energy

mechanism for Turkey is a debatable issue nowadays since the cost resulted from these payments is reflected to the electricity consumers by means of transmission tariffs. Furthermore, sustainability of the mechanism in the long term seems to be suspicious for Turkey considering other unsuccessful country experiences.

efficiency by establishing certain institutions, such as Energy Efficiency Coordination Committee (EECC)[7], and by enacting laws and regulations. Particularly since 2007, there have been quite a number of legislations on energy efficiency. The Ministry of Energy and Natural Resources (MENR) and its General Directorate of Renewable Energy and Energy Efficiency Coordination Board have carried out studies on energy efficiency policies, strategies and programs by working in coordination with other relevant institutions and organizations.

Main legislations on energy efficiency since 2007 are summarized in Figure 2.10.

Figure 2.10 Main legislations on energy efficiency in Turkey since 2007
Source: *author's own illustration.*

Turkey initiated its efforts for instigating energy efficiency measures by the enactment of Energy Efficiency Law No. 5627 in 2007. Energy efficiency policies in Turkey are mainly based on the legal framework of Law No. 5627. The purposes of this law are to increase energy efficiency, prevent waste, diminish the burden of energy costs on the economy and preserve the environment (Energy Efficiency Law, 2007). The scope of the law is highly broad, and it proposes various regulations for the generation, production, transmission, distribution and consumption of energy at industrial establishments, buildings, power generation plants, transmission and distribution

[7] The EECC was established in 1981 by the Prime Ministry and continued its work under the body of MENR after 1984 (Ceylan, 2010).

networks and transportation. Moreover, it proposes policies on raising energy awareness in the public and increasing use of renewable energy sources. The law defines energy efficiency as “reducing energy consumption without causing any decline in the living standards and service quality in buildings, and production quality and quantity in industrial establishments” (Energy Efficiency Law, (2007), p.2). Pursuant to the law, Energy Efficiency Coordination Board was established in the same year to carry out energy efficiency studies within all relevant organizations all over the country, monitor results of these studies and implement policies. Furthermore, it is mentioned in the law that the regulations on energy requirements for buildings about insulation characteristics, efficiency of heating and/or cooling systems and energy consumption classification of electric motors, electrical home appliances, air-conditioners, and light bulbs will be laid down by relevant institutions and organizations.

In accordance with the EU law adaptation process and Energy Efficiency Law, a regulation called “Building Energy Performance Regulation” (BEP) came into force in 2008. This regulation is based on the TS 825 Thermal Insulation Requirements in Buildings introduced in 2000, which is a standard under BEP at present. Within the scope of this regulation, some performance criteria and standards on architectural, thermal insulation, heating and cooling systems and electrical wiring issues for buildings are determined (BEP, 2008). The buildings that do not meet these criteria and standards are not allowed to have building licenses any more. On the other hand, Energy Performance Certificates in order to provide information on energy expenses and CO_2 emissions of buildings are compulsory by BEP for new buildings starting from January 1, 2011. Nonetheless, the deadline for existing stock (built before 2011) has been extended from 2017 to 2020. Thus, Turkey aims to convert at least a quarter of its 2010 building stock into sustainable buildings by installing heat insulation and energy-efficient heating systems in all commercial and service buildings (IEA, 2017).

National Climate Change Strategy (2010-2020) and National Climate Change Action Plan (2011-2023) were developed mainly to contribute to global efforts to reduce the impacts of climate change. In the scope of these plans, a set of objectives for different sectors takes place (industrial, agricultural, transportation, buildings etc.) in line with the basic principle of the United Nations Framework Convention on Climate Change. Contribution to global greenhouse gas emission mitigation, adaptation to climate change, increasing access to financial resources for mitigation and adaptation activities, developing national research, development and innovation capacities, increasing national preparedness and capacity, and raising public awareness are the strategic targets proposed in Ministry of Environment and Urbanization (2011).

Electrical appliances are responsible for the most of electricity consumed at homes. Therefore, their being efficient plays an important role in decreasing electricity consumption. Labelling programs on electrical appliances were firstly introduced in Turkey in 2002 parallel to EU directives and, since then mandatory labelling policies for many products have been implemented incrementally (Aydın, 2018). Turkey has largely adopted product efficiency standards along with the EU Eco-design Directive in 2010. New regulations for more efficient home appliances, which would complement and improve existing efficiency legislation Law No. 5627 and be in accordance with the Directive, became effective in 2012. Notifications on energy labelling on dishwashers, washing machines, refrigerators and televisions were published. Main purpose of these notifications is to determine the obligations of supplying information on labelling and additional product information. In the scope of these notifications, some obligations are imposed on producers and sellers. To illustrate, indicating energy efficiency class information of the product in their advertisements is compulsory for both producers and sellers (Kama and Kaplan, 2013).

In 2012, Energy Efficiency Strategy Document was published. It targets to improve energy intensity of Turkey at least by 20% in 2023 compared to 2011. Furthermore, reducing energy intensity and energy losses in the industry and service sectors, decreasing energy demand and carbon emissions of buildings, promoting sustainable environment friendly buildings that use renewable energy sources, and providing market transformation of energy efficient products are other targets included in this document published by Ministry of Energy and Natural Resources (2012).

In the Tenth Development Plan covering 2014-2018 period, energy efficiency improvement program is discussed, and some important goals like encouraging energy efficiency in different sectors such as industry, dwellings and transportation are set. In line with 2023 targets, the plan focuses on supplying uninterrupted, qualified, secure, minimum cost energy to the end-user and providing resource diversification in the energy supply. The main target on energy as part of the plan is to fulfill a competitive energy system that will concentrate on the use of domestic and renewable energy resources, realize the use of nuclear energy in the electricity production and enable the reduction in energy intensity while considering environmental impacts of energy use (Ministry of Development, 2014)

MENR Strategic Plan covering 2015-2019 period makes the issues of security of supply and resource diversity, energy saving and efficiency the key focus areas. The mission of the plan is defined as providing the highest possible contribution to national prosperity by using the existing energy resources most efficiently and environmentally consciously (Ministry of Energy and Natural Resources, 2015).

In 2017, National Energy Efficiency Action Plan (2017-2023) was published. As part of this Action Plan, the policies for the sectors of buildings and services, energy, transport, industry and technology and agriculture are developed to decrease energy intensity. According to Ministry of Energy and Natural Resources (2018), energy savings are expected to be 23.9 MTEP cumulatively by investing 10.9 billion USD by 2023, and primary energy consumption of Turkey is expected to decrease by 14% between 2017 and 2023.

CHAPTER 3

LITERATURE REVIEW ON ENERGY EFFICIENCY

Today, efficiency measurement is used in various fields such as banking, agriculture and health care sectors. Energy is also one of the prominent sectors on which academic and empirical studies concentrate. Recently, studies estimating efficiency of electricity and gas distribution networks or efficiency in energy use have constituted a large part in the field of energy economics.

In this chapter, the studies measuring energy efficiency at different levels such as aggregate, industrial, residential etc. based on input demand functions with Stochastic Frontier Analysis (SFA) for different countries will be introduced in brief. Furthermore, among these studies, those concentrating on residential energy efficiency will be discussed in more detail in terms of the variables used in the models and their results. After introducing the energy efficiency studies on Turkey, the contribution of our study to the literature will be specified.

3.1 Studies Measuring Efficiency in Primary Energy Use Based on Input Demand Functions with Stochastic Frontier Analysis

The study of Filippini and Hunt (2011)[8] for OECD countries aroused an interest in energy efficiency literature since it is the first study that combines input demand function and SFA to measure efficiency in primary energy use. This new approach has been adopted in the literature a lot.

[8] In the study, which measures energy efficiency of 29 OECD countries between 1978 and 2008, Turkey is also one of the countries whose energy efficiency is assessed. The results indicate that Turkey takes place among the countries using energy inefficiently.

Based on the same approach, the studies of Zaidi (2016)[9] for Asian countries, Kipouros (2017) for developing countries and Adom et al. (2018) for African countries aim to conduct cross-country estimations. On the other hand, there are also country-specific studies such as Filippini and Hunt (2013) for the USA, Otsuka and Goto (2015) and Otsuka (2016) for Japan, and Filippini and Zhang (2016) for China.

Other than these studies measuring energy efficiency at the aggregate level, there are also studies focusing on industrial energy efficiency such as Lundgren et al. (2016), Lutz et.al (2017) and Boyd and Lee (2019).

All of these studies have contributed extensively to the energy demand frontier literature in terms of the variables included and different SFA specifications used in the models.

3.2 Studies Measuring Efficiency in Residential Energy Use Based on Input Demand Function with Stochastic Frontier Analysis

The number of studies analyzing energy efficiency at the residential level remains relatively limited compared to those at the aggregate or the industrial level. Nonetheless, they have recently started to become popular among researchers.

The study by Filippini and Hunt (2012) stands out in the literature as the first study that applies Filippini and Hunt (2011) approach to the residential sector. It estimates residential aggregate energy demand function for 48 states of the USA, and measures underlying energy efficiency for each state as well as relative efficiency across the states over the period 1995-2007.

[9] In the study, which measures energy efficiency of 19 Asian countries including Turkey between 1980 and 2013, Turkey is found to be among the most inefficient countries especially during the period of 2000-2013.

After this study, residential efficiency literature has flourished rapidly by means of many subsequent studies. Filippini et al. (2014) analyze the impact of energy performance standards of buildings, heating systems and electrical appliances, financial incentives and informative measures on residential energy efficiency of 27 EU countries from 1996 to 2009. The findings suggest that energy performance standards and financial incentives are vital to improve energy efficiency.

Adetutu and Ajayi (2015) aim to model the impact of cross-country heterogeneity on residential energy efficiency for 17 African countries between 1980 and 2011. In the model, inefficiency effects are explained by share of renewable and alternative energy technologies in total energy use, industrial share of value added, level of political rights, population density, trade openness, urbanization rate and a dummy for presence of energy subsidies. It concludes that cross-country variation in energy efficiency levels is highly influenced by national characteristics. The results indicate that countries with higher levels of industrialization, population density, urbanization rate and energy subsidies are more inefficient in energy use compared to others. On the other hand, trade openness plays an important role in increasing efficiency since technology spills over across countries through the channel of trade flows. Moreover, countries with higher shares of renewable and alternative sources of energy and better institutions without bureaucratic and organizational barriers that limit energy-saving investments are more energy efficient.

Otsuka (2018) estimates residential energy demand function of Japan’s 47 prefectures from 1990 to 2010 and analyses the effect of certain factors on efficiency levels such as electrification rate and population density. The empirical results point out that increasing electrification and population density contribute significantly to the improvement in energy efficiency.

Other than these studies focusing on aggregate energy efficiency for residential sector, there are also certain studies concentrating on a specific type of energy, namely electricity.

Marin and Palma (2015) measure residential electricity efficiency for 10 EU countries in the use of two groups of appliances, namely cooling appliances (refrigerators and freezers) and washing appliances (dishwashers and washing machines) for the period 1995-2013. In the model, inefficiency effects are explained by domestic and foreign technology measures derived from patent, import and domestic production information. The study infers that development of domestic and foreign technologies improves efficiency in use of electricity since they enable rapid diffusion of energy efficient appliances and, therefore increase overall energy efficiency.

Weyman-Jones et al. (2015) employ a cross-sectional disaggregated dataset obtained from an interview carried out in 2008 to measure efficiency in electricity use of Portuguese households. Electric heating and electric water heating ownerships are used to account for inefficiency effects. The results show that these two variables have no impact on efficiency.

Broadstock et.al (2016) use a dataset obtained from a survey conducted in 2012 and try to analyze electricity consumption and efficiency of Chinese households. Besides a model assessing all households' efficiency, three separate models are also estimated for households living in cities, towns and villages. In all models, inefficiency effects are explained by environmental perception, frequency of power failure, ownership of financial assets, health status, education level of head of the household, use of other energy resources such as firewood and access to clean water sources. The findings suggest that energy efficiency of Chinese households is on average around 63% in 2012. This implies that they could have used 37% less electricity to produce the same amount of energy services. Therefore, Chinese households have an important energy saving potential. A striking result is that households living in cities with the highest income level and having access to the best technologies are the least efficient ones, whereas those living in villages are the most efficient. This result is attributed to inherent tendency of people living in cities to consume more and their lack of understanding how to use goods more efficiently. Furthermore, the study infers that power failures and increasing education level have a negative impact on efficiency.

Having environmental awareness does not create an improvement in efficiency. On the other hand, poor health status and less financial assets, use of other energy sources such as firewood and access to clean water resources have a significant effect on increasing efficiency.

Otsuka (2017) models residential electricity demand of Japan’s 47 prefectures from 1990 to 2010 and tries to explain inefficiency effects with household size, household floor area and ageing population ratio. The findings suggest that the increase in household size and decrease in floor area improve households’ efficiency in electricity use.

3.3 Energy Efficiency Studies on Turkey

Among the studies conducted on efficiency for Turkey, there is no study utilizing the approach proposed by Filippini and Hunt (2011). The efficiency studies mostly concentrate on country comparisons including Turkey in relation to OECD or European countries, and commonly use Data Envelopment Analysis (DEA) rather than SFA as the method of analysis.

Ceylan (2010) applies two different input-oriented DEA models with single output and two outputs to assess energy efficiency of 27 EU countries and 5 non-EU countries including Turkey for the period 1995-2007. In both models, capital, labor and research and development expenditures are non-energy inputs, while solid fuels, crude oil, petroleum products, natural gas, nuclear and renewable energy are energy inputs. On the other hand, GDP is the output of the single output model, whereas GDP and greenhouse gas emissions are the outputs of the two-output model. The results of both models point out that Turkey’s energy efficiency performance is remarkably high among 32 countries in almost every year. However, this is attributed to its lower use of capital stock and industrialization rate relative to most of the developed European countries considering the logic of DEA. Ceylan (2010) also tries to determine the factors affecting energy efficiency by using relative energy efficiency scores obtained from the two-output model. As a result, increasing energy prices and rising share of renewable energy sources rather than oil and solid fuels in total energy consumption have a positive impact on energy efficiency of a country, whereas higher fixed capital formation leads to more inefficiency.

Şimşek (2011) conducts a cross-country study that evaluates energy efficiency of 24 OECD countries from 1995 to 2008 by applying super efficiency DEA model and the DEA model with an undesirable output. In both models oil, coal, natural gas, hydropower and nuclear energy are taken as energy inputs, while capital and labor are used as non-energy inputs. GDP is the output of super efficiency model, while GDP and greenhouse gas emissions are the outputs of the model with an undesirable output. Findings of both models reveal that Turkey emerges as one of the most inefficient countries except the years 1995, 2005 and 2006. However, Şimşek (2011) points out that being one of the most inefficient countries in the model with an undesirable output does not imply that Turkey is one of the most polluting countries among OECD countries. Although it is a heavily fossil fuel dependent country in energy use, its greenhouse gas emissions per capita are lower than many OECD countries. On the other hand, the main problem of Turkey as an import dependent country is that it is not able to use even its imported energy sources efficiently in the production process.

Düzgün (2014) applies DEA to measure energy efficiency of 15 EU countries and Turkey over the period 2000 to 2011. Capital, labor and energy are the inputs in the model, whereas GDP and greenhouse gas emissions are the desirable and undesirable outputs, respectively. The study reveals that Turkey is one of the most inefficient countries during twelve-year period. Moreover, there is a sharp fall in energy efficiency in 2002 resulting most probably from 2001 financial crisis. Though there is an improvement in energy efficiency of Turkey after 2007 parallel to the enaction of Energy Efficiency Law no. 5627, its performance is unsatisfactory in general compared to the European countries.

Considering the results of all these studies, Turkey seems to be an energy inefficient country, and contrary to the findings of Ceylan (2010), its performance has not improved over time. Besides these studies focusing on energy efficiency at the aggregate level, there are also researches dealing with industrial energy efficiency.
Yerlikaya (2004) selects 22 Turkish private manufacturing industries at three-digit level based on International Standard Industrial Classification and estimates their technical efficiency levels with SFA for the years 1985, 1990 and 1995. In the model labor, capital and electricity consumption are the inputs, and real value added is the output. The findings show that variations in real value added in 1985 and 1990 are mainly due to inefficient use of inputs, whereas those in 1995 are explained by random shocks. Moreover, capital is found to have a strong positive impact on real value added of manufacturing industries.

Önüt and Soner (2007) evaluate energy efficiency of 20 medium size companies in metallic goods industry by using input oriented DEA model. The input variables in the model are electricity, natural gas, oil and LPG consumptions, whereas the output variables are total sales and profits. The results reveal that majority of the companies are inefficient, but there are also potentials to save energy for these companies. In the study, some company-based suggestions are made in order to improve their energy efficiency levels.

Due to lack of data availability and reliability, studies related to energy efficiency for Turkey's provinces are scarce. The studies of Köne and Büke (2012), Özkara and Atak (2015) and İlhan (2015) are rare examples of this literature.

Köne and Büke (2012) compare the performance of 54 Turkish provinces in terms of urban air pollution for 1990 and 2000 by using output oriented DEA model. Fossil fuel consumption and population are the inputs in the model, whereas GDP is the desirable output, and sulfur dioxide and particulate matter are undesirable outputs. The findings point out that only four provinces (Bingöl, Bolu, Kocaeli and Siirt) out of 54 are efficient in terms of producing more GDP and less emission for both years, and there is a positive relationship between GDP and efficiency scores of provinces. Furthermore, Industrial Districts such as Çanakkale, Konya and Tekirdağ have lower efficiency levels compared to other developed provinces.

Özkara and Atak (2015) investigate total-factor energy efficiency and electricity saving potential of manufacturing industry for 26 regions of Turkey between 2003 and 2012 by setting up four different DEA models. In the models labor, capital and electricity consumption are the inputs, while production value and CO_2 emissions are the desirable and undesirable outputs, respectively. The results suggest that Turkish manufacturing industry has an important electricity saving potential of 39.7% during this ten-year period. Based on favorable DEA model, the region including İstanbul, which is economically the largest and the most industrialized region of Turkey, is found to be the most efficient, while the region including Gaziantep, Adıyaman, Kilis is the least efficient one. Moreover, the findings indicate that there is a U-shaped relationship between gross value added per capita and efficiency levels of regions.

İlhan (2015) measures urban energy efficiency levels of 81 Turkish provinces for 2012 by using DEA and assesses the factors affecting efficiency. In the model population, land area, energy consumption per capita, heating and cooling degree days are the inputs, whereas annual income, life expectancy and CO_2 emissions are the outputs. The results reveal that average energy efficiency score of Turkey for 2012 is approximately 0.9 which means that it could have used 10% less resources to produce the same amount of output. Moreover, Kocaeli and Tunceli are found to be the most efficient provinces, whereas Aksaray, Ankara, Elazığ, Konya and Malatya are the least efficient ones.

In relation to residential energy efficiency, Morgül (2014) tries to determine the patterns in electricity consumption and energy efficiency attitudes of Turkish households based on an internet survey conducted in 2013-2014 with more than 500 participants. In the study, cross-tabulation method, which analyzes the relationship between multiple variables quantitatively, is used and some inferences on electricity consumption of clustered households are made. The survey results point out that being well informed on energy labelling, peak hour usage, smart meters[10], standby consumption[11] and the efficient use of certain electrical appliances such as kettle, electric teapot, coffee machine etc. play an important role in improving residential efficiency in electricity use.

Aydın (2018) analyzes the impact of mandatory energy efficiency labels for household appliances on residential energy efficiency. The study uses 2010 and 2011 Household Expenditure Surveys conducted by TurkStat to derive the variables included in the model. In the study "move-in" year to the house is used as a proxy for the purchase of new appliances to replace the old ones. It is assumed that labelling regulation can affect electricity consumption only through the purchase of new appliances and people moving into new houses tend to purchase new appliances. In this way, it is aimed to reveal whether labelling regulation on electrical appliances after 2002 have become effective in reducing households' electricity consumption or not. The results confirm this hypothesis and suggest that the labelling regulation led to a reduction in residential electricity demand. The households who moved into their dwellings after 2002 consume 5% less electricity between 2002 and 2010 compared to those who moved before the regulation.

In these two studies, i.e., Morgül (2014) and Aydın (2018), parametric or non-parametric frontier methods such as SFA or DEA are not utilized to determine the level of households' energy efficiency. Morgül (2014) makes some inferences on the factors affecting residential electricity use based on descriptive statistics obtained from participants' responses, whereas Aydın (2018) mainly concentrates on the impact of

[10] A smart meter is an electronic device that is used to record consumption of electric energy and gives the information to the electricity supplier about monitoring and billing. Using a smart meter helps households to control their consumption in addition to their billings.

[11] Standby energy consumption corresponds to the energy consumed by a device when not in present use, but plugged in to a source of power and ready to be used, i.e., leaving televisions, computers, or other appliances open while not using.

labelling electrical appliances on electricity consumption by using Ordinary Least Squares (OLS) method. Thus, our study is the first one in this field since there is no other paper analyzing residential energy efficiency of Turkey and its determinants at the provincial level by using a frontier method.

CHAPTER 4

METHODOLOGY

In this chapter, concepts of efficiency and productivity will be discussed, and their differences will be explained briefly. After elaborating the approaches and methods on efficiency measurement, some prominent models based on SFA will be examined in detail. Lastly, the model proposed by Filippini and Hunt (2011) will be introduced in terms of its econometric specification and main contributions to the efficiency literature.

4.1 Efficiency vs. Productivity

Main purpose of this study is to measure efficiency in electricity use of Turkish households by using SFA. At this point, the approach proposed by Filippini and Hunt (2011) is our source of inspiration as for many other subsequent studies. This approach based on microeconomic production theory is motivated by the notion of non-radial input specific efficiency measurement introduced by Kopp (1981).

Before providing a thorough analysis of non-radial measure of energy efficiency, it is useful to clarify some basic concepts regarding efficiency and its measurement.

Efficiency is mainly described as the ratio of observed to optimal values of inputs or outputs. It is also described as the ability of attaining maximum output by using certain inputs given the technology (output maximization approach) or producing a certain amount of output from a minimum input combination (cost minimization approach). On the other hand, productivity is the ratio of the output produced to the input used in a production process.

Though efficiency and productivity are generally used interchangeably in the literature, they are not precisely the same thing since an increase in efficiency does not always result in an increase in productivity (Coelli et.al, 2005). Indeed, efficiency can be considered as only one of the main determinants of the productivity, and it is unlikely for an economic agent to provide productivity without providing efficiency. Furthermore, efficiency is mostly related to short term, whereas productivity is a long-term phenomenon (Odyakmaz, 2009).

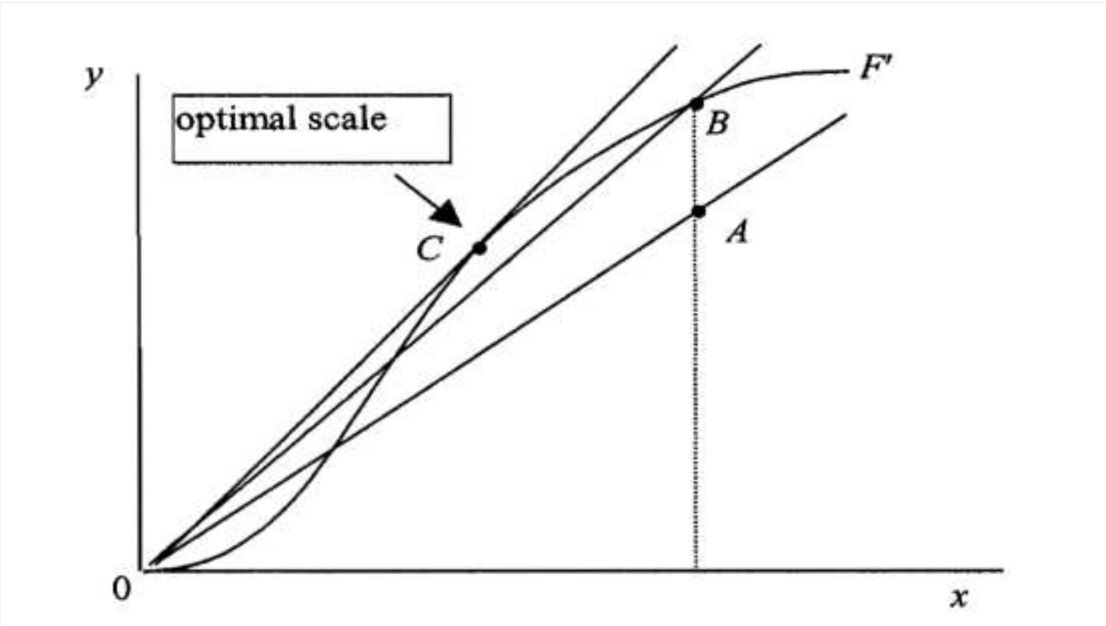

Figure 4.1 Productivity, technical efficiency and scale economies
Source: *Coelli et.al (2005, p.5)*

Figure 4.1, which displays a production frontier (F′) with one input (x) and one output (y), shows the amount of maximum output level that could be reached at each input level. Efficiency (mainly technical efficiency) is measured as the ratio of maximum output level to the observed output level given input. The firm is technically efficient at points B and C, but inefficient at point A since it can still increase its level of output without increasing the amount of input.

In addition to technical efficiency, Figure 4.1 illustrates also productivity and scale economies, and the slope of the ray, i.e., y/x provides a measure of productivity. When a firm at point A moves to technically efficient point B, the slope of ray, and so its productivity increases. The point C, where the ray from the origin is tangent to the production frontier, is actually the point of the maximum possible productivity (utilizing the scale economies). Thus, operating at any other point on the production frontier other than C results in a lower productivity. This indicates that a firm may be technically efficient, but it can improve its productivity by utilizing the scale economies.

Technical efficiency is an important concept since it takes into consideration also the ability of a production process' transforming inputs to outputs besides amount of the inputs (Çakmak, et.al, 2008). On the other hand, if the price information is available under the assumption of profit maximization or cost minimization, another type of efficiency related to the physical quantities arises, i.e., "allocative efficiency". In principle, allocative efficiency requires selecting the mix of inputs that produce the given amount of output at minimum cost. The combination of the technical and allocative efficiency provides "productive efficiency" (overall economic efficiency). Productive efficiency is defined as the ability of a production organization to produce a well-specified output at minimum cost (Kopp, 1981).

4.2 Efficiency Measurement

In the literature, there are two different approaches regarding the type of efficiency measure, namely, input and output oriented efficiency measures. Input oriented efficiency measure is mainly grounded on minimizing the amount of inputs to produce a certain level of output. Therefore, it addresses the question of "By how much can input quantities be reduced without changing the output produced?" (Coelli et.al, 2005). On the other hand, output oriented efficiency measure is based on maximizing the level of output produced given the amount of input. Thus, it addresses the question of "By how much can output quantities be expanded without altering the inputs used?" (Coelli et.al, 2005). Our study is an example of input oriented efficiency measure since we aim to measure how successful the households are to produce certain amount of energy services by using minimum amount of electricity.

After defining the concept of efficiency, another important issue arises, namely, how to measure efficiency. There are two fundamental approaches for efficiency measurement: radial measure proposed by Farrell (1957) and non-radial measure proposed by Kopp (1981) based on the Farrell’s work as seen in Figure 4.2.

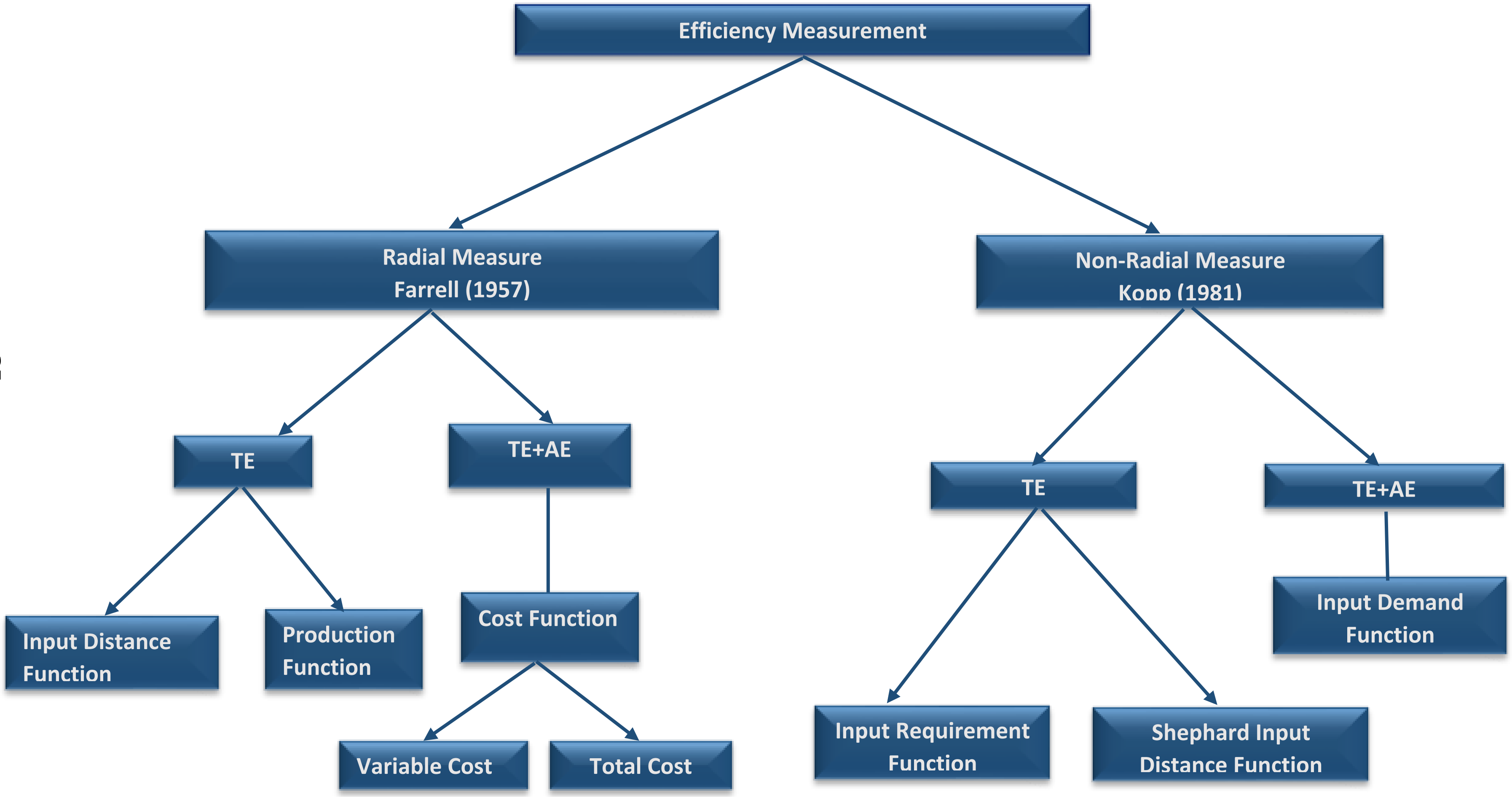

Figure 4.2 Overview of measurement of efficiency

Source: *Boogen (2017, p.291)*

TE: Technical Efficiency, AE: Allocative Efficiency

Farrell's efficiency measure combines both technical and allocative efficiency of multiple factors in single indexes, so they are also called multiple-factor efficiency measures. In this approach, efficiency of all inputs used in the production process is assessed, and it is assumed that a proportional decrease in all inputs is realized with an improvement in efficiency. Moreover, efficiency is measured based on input distance, production and cost functions. Nonetheless, this approach fails to identify individual factor efficiency, i.e., the contribution of each factor to the productive efficiency. Furthermore, there can be situations in which efficiency of only one input is the matter of interest. In the real world, there are often situations where some of the inputs are fixed or quasi-fixed (Boogen, 2017). In this case, instead of Farrell's approach, an input-specific or single factor (or non-radial) efficiency measure introduced by Kopp (1981) can be utilized. In this approach, different function types such as input requirement, Shephard distance and input demand functions are used to measure efficiency.

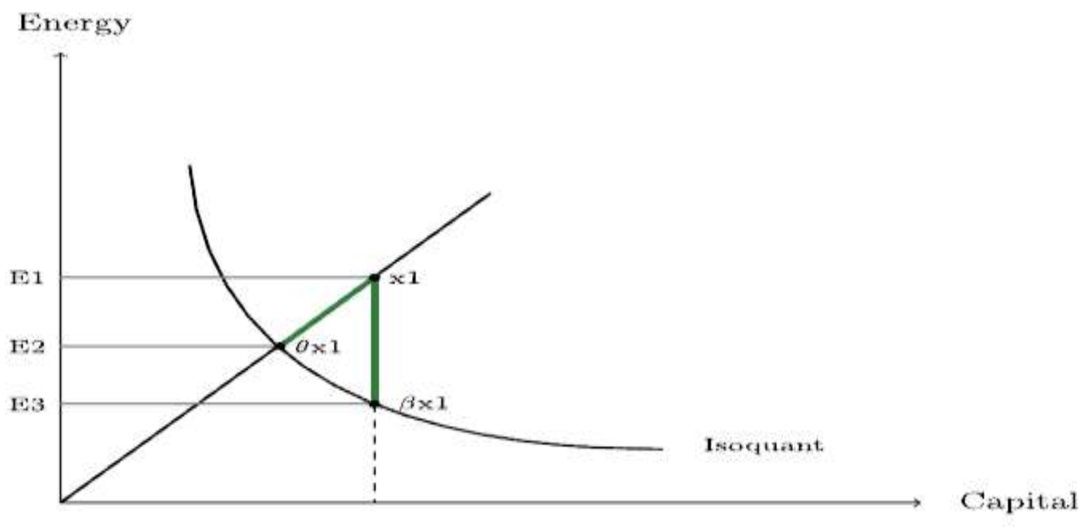

Figure 4.3 Difference between radial and non-radial measure of energy efficiency
Source: *Boogen (2017, p.290)*

Figure 4.3 is beneficial to examine the difference between radial and non-radial measures of energy efficiency graphically. The isoquant simply shows different combinations of capital and energy to produce a given amount of energy services.

Radial technical efficiency corresponds to the distance between x1 and θx1, and it implies that capital and energy decrease proportionally with an improvement in efficiency. On the other hand, non-radial technical efficiency is expressed as the distance between x1 and βx1, and it implies that energy decreases with an improvement of efficiency where capital is fixed.

After deciding to apply radial or non-radial approach, it is also important to determine the most appropriate method and functional form to measure efficiency. At this point, some basic information will be provided on the differences between measurement methods, i.e., frontier vs. non-frontier, parametric vs. non-parametric or stochastic vs. deterministic methods, and some types of functions that are used in the literature (Figure 4.4).

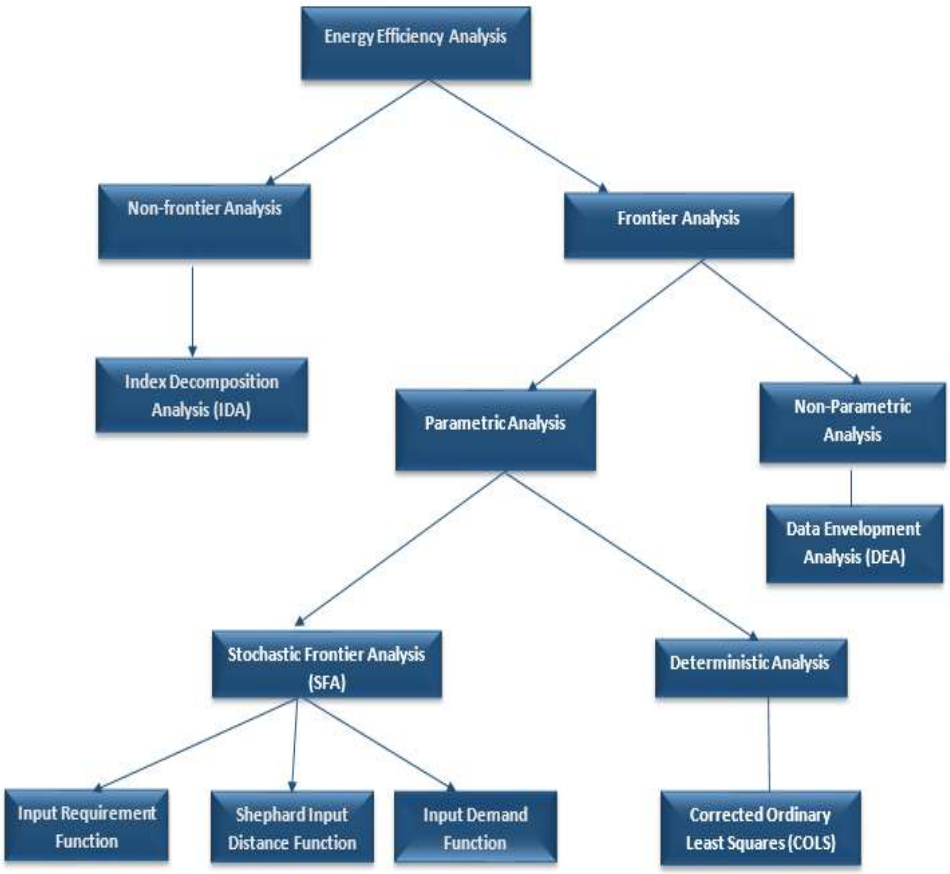

Figure 4.4 Methods to measure energy efficiency
Source: *Kipouros (2017, p.35)*

In the literature, there are frontier and non-frontier methods proposed to measure energy efficiency instead of relying on the classical efficiency indicators. For example, Energy/GDP ratio, namely, the ratio of total primary energy use to GDP is one of the most popular aggregate monetary-based energy efficiency indicators. This ratio mainly measures energy consumption of an economy at the most aggregate level, and its inverse is regarded as the measure of energy efficiency. However, this indicator, which is mostly preferred for the sake of its simplicity, cannot distinguish the changes unrelated to efficiency. At this point, Index Decomposition Analysis (IDA) as a bottom-up approach is one of the non-frontier methods that can be used. It aims to create an economy-wide composite energy efficiency index that separates factors affecting energy efficiency from non-efficiency ones (Ang, 2006)[12].

Different from the non-frontier methods, a frontier analysis with parametric and non-parametric versions focuses on the notion of determining the best frontier for energy use and calculates energy efficiency as the difference between actual energy use and optimal energy use predicted by a frontier (Filippini and Hunt, 2011).

In general, non-parametric approaches use production and cost functions, while in parametric methods production, cost or input demand functions are utilized. Although there is no consensus in the literature regarding which method to choose, and this is still a controversial issue, the parametric and non-parametric techniques have their own merits and demerits.

The main advantage of parametric approaches over non-parametric approaches is that they enable the researchers to separate the inefficiency component from the statistical noise related to measurement errors, inadvertent omission of relevant variables etc. Contrarily, non-parametric methods evaluate any deviation from the frontier as inefficiency and they tend to give a lower mean technical efficiency. Parametric methods with their ability of modelling unobserved heterogeneity in the production of

[12] For a more general discussion on IDA methods, see Ang (2006).

energy services are more appealing among the researchers (Filippini and Hunt, 2015). They also offer researchers to test some hypotheses concerning goodness of fit of the model constructed. Compared to the parametric ones, non-parametric methods are more sensitive to the outliers (Musa et.al, 2015).

Considering the virtues of non-parametric methods over the parametric ones, their computations are easier and they do not have as many assumptions as their parametric counterparts. Determining a specific functional form for the frontier is actually a difficult task since a wrong choice may have an influence on the results. Thus, non-parametric methods free of determining a specific functional form may be more preferable among the researchers. Lastly, the maximum likelihood estimation, on which parametric methods generally rely, may fail to assess the reliability of inferences in small number of Decision Making Units (DMUs), and it requires a large number of observations. Nevertheless, it is essential to take into consideration that studying on this small number DMUs may bring about inherently quite high average level of efficiency scores for non-parametric methods (Bezat, 2009).

Parametric methods are also divided into the methods utilizing deterministic and stochastic approaches. Førsund et.al (1980) point out that deterministic models rule out the very real possibility that an economic agent's performance can be influenced by factors completely outside its control such as poor machine performance, bad weather, input supply breakdowns as well as inefficiency. Thus, using deterministic models may be more appropriate for controlled environments, in which it is unlikely for economic agents to be affected differently by given factors (Silva et.al, 2018). Moreover, these models label all these effects as "inefficiency" without considering exogenous shocks, measurement errors and misspecification problems, which makes it a questionable approach (Førsund et.al, 1980).

Among the non-parametric and deterministic methods, DEA is the most prominent one and is frequently used by many researchers from different fields. This method based on the study by Farrell (1957) was proposed by Charnes, Cooper and Rhodes (1978).

It is a mathematical method using linear programming techniques to estimate relative efficiencies of homogeneous DMUs. Relative efficiency is calculated as the ratio of the total weighed output to the total weighed input. In principle, this ratio determines how efficient a DMU is in producing a certain level of output given the amount of input compared to similar DMUs (Mardani, 2017).

Corrected Ordinary Least Squares (COLS) proposed by Gabrielsen (1975) is the deterministic but parametric counterpart of DEA. It is a method applied in two steps. In the first step, OLS is used. As a result, consistent and unbiased estimates of the slope parameters and consistent but biased estimate of the intercept parameter ($\widehat{\beta_0}$) are obtained. In the second step, this bias for $\widehat{\beta_0}$ is corrected by using maximum of estimated inefficiency terms, i.e., max ($\hat{u}_i$) (Kumbhakar and Lovell, 2000).

DEA and SFA are two prominent methods in the efficiency measurement. "*The DEA and SFA methods are not direct competitors but rather complements: in the tradeoff between DEA and SFA something is sacrificed for something to be gained.*" (Kuosmanen et.al, 2015, p.193). Nonetheless, the choice between these two methods relies on certain factors (Sarafidis, 2002). SFA can be preferred to DEA when it is possible to specify the functional form of the frontier correctly and omitted variables may have an influence on the results. Moreover, in SFA some statistical tests can be used for model specification and determination of significance of the variables in the model. Nevertheless, if there is a remarkable correlation between the regressors and if it is difficult to determine the correct functional form of the frontier, then DEA rather than SFA can be chosen.

The functions used in SFA to measure energy efficiency can be categorized as input requirement functions, Shephard input distance functions and input demand frontier functions[13]. While both input requirement and Shephard input distance functions provide information on only technical efficiency, input demand frontier functions give

[13] For further information on econometric specifications of these functions, see Filippini and Hunt (2015) and Kipouros (2017).

information on overall efficiency, i.e., both technical and allocative efficiency. Moreover, input demand frontier functions require information on input prices since conditional stochastic energy demand is derived from a cost minimizing process and costs are determined with respect to the input prices (Filippini and Hunt, 2015). On the other hand, energy requirement and Shephard energy distance functions regressing energy on other inputs and outputs, potentially suffer from endogeneity problem (Kipouros, 2017). In the literature there are some studies trying to cope with this problem such as Guan et al. (2009), in which two-step approach is adopted for the estimation of an input requirement function when endogeneity exists.

Table 4.1 aims to summarize some prominent studies in the literature using these three functions. It is obvious that Shephard input distance and input demand frontier functions are used more frequently compared to the input requirement functions.

Table 4.1

Applications based on different functions to measure energy efficiency

Study	Type of Function	Topic of Study
Boyd (2008)	Input requirement function	Energy use in corn milling plants in the US
Khayyat and Heshmati (2014)	Input requirement function	Energy use in Korean industry
Lin and Wang (2014)	Input requirement function	Energy use in China’s iron and steel industry
Zhou et al. (2012)	Shephard input distance function	Energy use in OECD countries
Lin and Du (2013)	Shephard input distance function	Energy use in China
Lin and Long (2015)	Shephard input distance function	Energy use in Chinese chemical industry
Adetutu et al. (2015)	Shephard input distance function	Energy use in 55 countries including OECD and non-OECD
Lin and Wang (2016)	Shephard input distance function	Energy use in Chinese commercial sector
Li et.al (2017)	Shephard input distance function	Energy use in Chinese 30 provinces
Shen and Lin (2017)	Shephard input distance function	Energy use in Chinese 30 sub-industries
Du et.al (2018)	Shephard input distance function	Energy use in Chinese 30 provinces
Homma and Hu (2018)	Shephard input distance function	Energy use in Japanese regions
Xie et.al (2018)	Shephard input distance function	Energy use in China’s transport sector
Filippini and Hunt (2011)	Input demand function	Energy use in OECD countries
Filippini and Hunt (2012)	Input demand function	Energy use in the US
Filippini et al. (2014)	Input demand function	Energy use in the EU
Marin and Palma (2015)	Input demand function	Electricity use 10 EU countries
Orea et al. (2015)	Input demand function	Energy use and rebound effect in the US
Otsuka and Goto (2015a)	Input demand function	Energy use in Japanese regional economies
Weyman-Jones et al. (2015)	Input demand function	Electricity use in Portuguese households
Broadstock et al. (2016)	Input demand function	Residential electricity use in China.
Filippini and Hunt (2016)	Input demand function	Residential energy use in the US
Filippini and Zhang (2016)	Input demand function	Energy use in Chinese provinces
Lundgren et al. (2016)	Input demand function	Energy use in 14 Swedish manufacturing sectors
Adom et. al (2018)	Input demand function	Energy use in 22 African countries
Alberini and Filippini (2018)	Input demand function	Residential energy use in the US

Source: *Author’s own elaboration, based on Boogen (2017) and Kipouros (2017)*

In our study, we can specify the functional form of the residential electricity demand frontier. Moreover, we want to apply some statistical tests for the significance of the variables in our model. Nonetheless, it is unlikely to include all of the variables affecting residential electricity demand into our model at the provincial level. Therefore, considering also inadvertent omission of relevant variables case, we opt to use SFA as the method of analysis. Moreover, we utilize an energy demand frontier function in our analysis to avoid the endogeneity problem.

In the rest of this chapter, we will concentrate on SFA and the study of Filippini and Hunt (2011).

4.3 Stochastic Frontier Analysis

Stochastic frontier models that have a widespread use in the efficiency literature were independently proposed by Aigner et.al and by Meeusen and van den Broeck in 1977 for a production function specified for cross-sectional data as follows:

$$\ln q_i = x_i'\beta + v_i - u_i \tag{4.1}$$

where q_i is the output of the i-th firm, x_i is a kx1 vector containing the logarithms of input quantities of the i-th firm, β is a vector of the unknown parameters and u_i is non-negative random variable related to technical inefficiency that is assumed to be distributed as half-normal.

The term v_i introduced into the model is the statistical noise (symmetric random error term) associated with inadvertent omission of relevant variables from the vector of x_i measurement, sampling and model specification errors. This term transforms the deterministic frontier model into the stochastic one.

A Cobb-Douglas stochastic frontier model has the following formula (Coelli et.al, 2005):

$\text{In } q_i = \beta_0 + \beta_1 \text{ In } x_i + v_i - u_i$

$\text{or } q_i = \exp(\beta_0 + \beta_1 \text{ In } x_i + v_i - u_i)$ (4.2)

$$\text{or } q_i = \underbrace{\underbrace{\exp(\beta_0 + \beta_1 \text{ In } x_i)}_{\text{deterministic component}} \text{ x } \underbrace{\exp(v_i)}_{\text{noise term}}}_{\text{stochastic component}} \text{ x } \underbrace{\exp(-u_i)}_{\text{inefficiency}}$$

where v_i can take negative or positive values, v_i~ iii $N(0, \sigma_v^2)$ and u_i~iii N' $(0, \sigma_u^2)$, v_i's and u_i's are independent of each other and the explanatory variables.

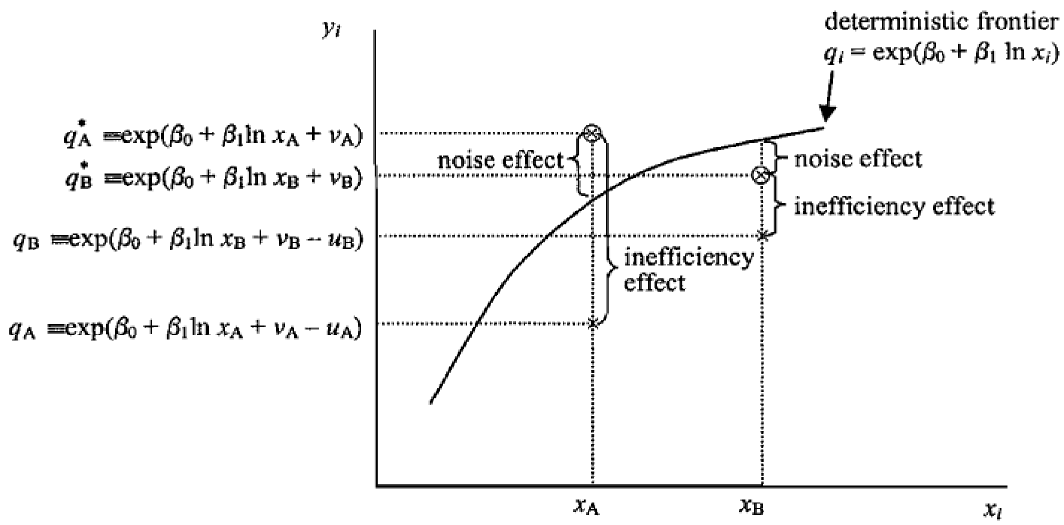

Figure 4.5 Illustration of stochastic production frontier
Source: *Coelli et al. (2005, p.244)*

In Figure 4.5, q_A^* and q_B^* show the frontier output levels produced by firms A and B, respectively, when there are no inefficiency effects, i.e., $u_A = 0$ and u_B=0. The statistical noise term v_i can take negative or positive values. Thus, the frontier output value q_A^* for firm A lies above the deterministic frontier if $v_A>0$, while frontier output value q_B^* for firm B lies below the deterministic frontier if $v_B<0$.

On the other hand, the observed output q_A and q_B lies below the deterministic frontier if there are inefficiency effects and the overall sum of the noise and inefficiency effects is negative, i.e., $v_A- u_A<0$ and $v_B- u_B<0$. In Figure 4.5, it is possible to observe the contribution of inefficiency effect and noise term to the deviation from the estimated frontier for both firms. To illustrate, the reason for deviating estimated frontier output for firm A is mostly due to inefficiency effects rather than the noise.

Determining the most appropriate method for predicting efficiency is also an important issue considering certain assumptions such as:

- $v_i \sim N(0, \sigma_v^2)$ with zero mean, homoscedastic variance and $E(v_i v_j)=0$ for all $i \neq j$
- $E(u_i^2)$ =constant and $E(u_i u_j) = 0$ for all $i \neq j$.

While these properties of the noise term v_i are the same with those in the classical regression model, this is not the case for the inefficiency term u_i with non-zero mean ($u_i \geq 0$). Since the composite error term $\varepsilon_i = v_i - u_i$ is asymmetric, i.e., $E(\varepsilon_i) \leq 0$, it is not possible to estimate the inefficiency term u_i by OLS (Çakmak et.al, 2008). Moreover, using OLS provides consistent estimators for the slope coefficients but downward biased estimator for the intercept coefficient. Thus, OLS is not a suitable method for computing (in)efficiency (Coelli et.al, 2005).

Kumbhakar and Lovell (2000) state that even if this bias in the OLS method is corrected, it is not possible to obtain the inefficiency term, since OLS method can only give information about the existence of the inefficiency. On the other hand, with its many large sample properties Maximum Likelihood Estimation (MLE) is asymptotically more efficient than OLS and COLS (Coelli et.al, 2005). Furthermore, a Monte Carlo simulation study investigating the finite sample properties of these two methods reveals that MLE should be preferred over COLS when the contribution of the technical inefficiency effects to the total variance of the output is relatively large, i.e., greater than 50 % (Coelli,1995).

The MLE method can be used in two different ways. In the first one, namely "Moments Method", the estimation procedure consists of two stages, i.e., firstly estimate all β parameters with OLS and then use the intercept parameter β_o to estimate v_i and u_i by MLE. On the other hand, in the second one, β parameters and u_i are simultaneously estimated by MLE method (Kumbhakar and Lovell, 2000).

The Aigner et.al (1977) model uses parametrization of the log-likelihood function under half-normality assumption of inefficiency terms where $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda^2 = \sigma_u^2 / \sigma_v^2 \geq 0$ such as:

$$\text{In L } (y/\beta, \sigma, \lambda) = -\frac{I}{2} \text{In } (\frac{\pi\sigma^2}{2}) + \sum_{i=1}^{I} \text{In}\Phi(-\frac{\varepsilon_i \lambda}{\sigma}) - \frac{1}{2\sigma^2} \sum_{i=1}^{I} \varepsilon_i^2 \tag{4.3}$$

where y is vector of log of outputs (q), $\varepsilon_i \equiv v_i - u_i = \text{In } q_i - x_i' \beta$ and $\Phi(x)$ is the cumulative distribution function of the standard normal random variables evaluated at x.

MLE is a method based on taking first derivatives with respect to unknown parameters and then equalizing them to zero. However, since first order conditions for the unknown parameters β, σ, and λ are non-linear and they cannot be solved analytically by SFA, a MLE method with iterative optimization procedure should be utilized, i.e., selecting the initial values for the unknown parameters and then updating them until these values maximize the log-likelihood function (Coelli et.al, 2005).

It is possible to obtain an estimate for the composite error term ε_i by using Equation 4.3, but not directly for the inefficiency component u_i. Hence, Jondrow et.al (1982) proposed a method based on the conditional probability distribution approach for separating the error term of the stochastic frontier model into its two components and estimating the level of technical efficiency for each observation in the sample such as:

$$TE_i = \exp(-\hat{u}_i) \quad \text{where } \hat{u}_i = E(u_i/\varepsilon_i) \tag{4.4}$$

Then, the measure of the technical efficiency of each firm by using output oriented production function is calculated as:

$$TE_i = \frac{q_i}{\exp(x_i'\beta + v_i)} = \frac{\exp(x_i'\beta + v_i - u_i)}{\exp(x_i'\beta + v_i)} = \exp(-u_i); \qquad 0 < TE_i < 1 \tag{4.5}$$

where the level of technical efficiency shows the output level produced by i-th firm compared to the output level produced by a fully efficient firm using the same inputs vector.

Although there are different distributional assumptions for the inefficiency term u_i such as half-normal (Jondrow et.al, 1982), truncated normal (Stevenson, 1980), exponential (Aigner et.al, 1977, Meeusen and van den Broeck, 1977), and gamma (Stevenson, 1980, Greene, 1990), which one to choose is actually a matter of question (Coelli et.al, 2005).

Coelli et.al (2005) argue that the preference of a particular distribution is related to the capability of the software program used. To illustrate, although FRONTIER can be used for only half-normal and truncated normal models, LIMDEP can be utilized for exponential and gamma models beside half-normal and truncated normal models. Another reason affecting this choice is that some distributions such as half-normal and exponential types have mode at zero, i.e., most of the inefficiency effects will be in the neighborhood of zero. Rather than these distributions, the ones having wider distributional shapes such as truncated normal and gamma can be opted by researchers. Nonetheless, even if different assumptions are made for the inefficiency terms, the efficiency ranks of the firms are unlikely to change relying on these distributional choices (Coelli et.al, 2005).

Another important issue is the choice of the functional form for the stochastic frontier. Indeed, there are some common functional forms used in the literature such as linear, Cobb-Douglas, quadratic, normalized quadratic, translog, Fourier flexible, generalized Leontief and CES (Constant Elasticity of Substitution). Nevertheless, which form to choose is a matter of question again, and even there are some studies specifically focusing on this selection issue such as Şahin (2002) and Umar et.al (2017). On the other hand, since there is no a priori reason for choosing one form over the other, the researchers should be aware of the drawbacks of each choice. To illustrate, although functions such as quadratic, normalized quadratic, translog, Fourier flexible, generalized Leontief, CES are more flexible compared to linear and Cobb-Douglas functions, this increasing flexibility may bring about some econometric problems such as multicollinearity (Coelli et.al 2005).

Up to now, cross-sectional version of the stochastic frontier analysis is discussed. Pitt and Lee (1981) extended cross-sectional analysis to panel data in terms of the following:

$$\ln q_{it} = x_{it}'\beta + v_{it} - u_{it} \tag{4.6}$$

where q_{it} is output of the i-th firm at time t, x_{it} is a k*1 vector of (transformations of the) input quantities of the i-th firm at time t and β is the vector of the unknown parameters.

Compared to cross sectional data, panel data analysis has an important virtue since it enables the researcher to investigate the changes in both technical efficiency and the production technology. As in cross-sectional data, assuming that the terms v_{it}'s and u_{it}'s independent of each other is reasonable also for panel data and this allows us to estimate parameters in the model and predict technical efficiency easily. Nonetheless, assuming that u_{it}'s are independent of each other, i.e., E ($u_{it}u_{jt}$) = 0 for all $i \neq j$ is not a realistic approach for the panel data since the efficient firms may remain efficient or the inefficient ones can improve their level of efficiency over time by learning from their past experience. Hence, a requirement for analyzing the behavior of the inefficiency effects arises, i.e., whether they are time varying or not (Coelli et.al, 2005).

Time-invariant models suggested by Pitt and Lee (1981) and Battese and Coelli (1988) assume that inefficiency does not change over time. Most known versions of these models are fixed effects and random effects models, in which $u_{it} = u_i$ and the term u_i is a fixed parameter or a random variable, respectively. Fixed effects models are estimated by OLS including dummy variables, whereas random effects models can be estimated by both OLS and MLE (Coelli et.al, 2005).

4.3.1 Battese and Coelli (1992) Model

Although the earlier models treat technical efficiency as time invariant, subsequent panel data models proposed by Cornwell et.al (1990), Kumbhakar (1990), Battese and Coelli, (1992,1995), and Lee and Schmidt (1993) permit technical efficiency to vary over time[14].

In the Battese and Coelli (1992) model, the stochastic frontier production function with N firms over T periods is specified as follows:

$$\text{In } q_{it} = x_{it}'\beta + v_{it} - u_{it} \qquad (4.7)$$

$$u_{it} = \eta_{it} u_i = \{\exp[-\eta\,(t-T]\}\, u_i, \qquad i=1, 2\ldots.N, \qquad t=1, 2\ldots T \qquad (4.8)$$

[14] In our study, we will focus only on Battese and Coelli (1995) model to measure energy efficiency. For the theoretical framework of other time invariant or time varying models, see Kumbhakar and Lovell (2000).

In this model, non-negative firm effects, u_{it}'s, are exponential function of time and they may change over time. Furthermore, the sign of the unknown parameter η in the model and its interpretation is crucial. The cases of $\eta > 0$, $\eta = 0$ or $\eta < 0$ imply that u_{it} decreases, remains constant or increases over time, respectively. Therefore, a positive sign of η points out a possible improvement in technical efficiency for a firm over time (Battese and Coelli, 1992).

In the model, gamma parameter (γ) actually proposed by Battese and Corra (1977) is defined as $\gamma=\sigma_u^2/(\sigma_v^2+\sigma_u^2)$[15]. This parameter takes the value between zero and one and indicates the importance of the inefficiency term. The case of γ=0 points out that there is no inefficiency in the model and deviations from the frontier are explained by the statistical noise term, i.e., the model is not different from the classic OLS model. Contrarily, the case of γ=1 indicates that the deviations from the frontier completely arise from the inefficiency, i.e., the model is not different from the deterministic model without the statistical noise term (Battese and Coelli, 1992).

The mean technical efficiency of the i-th firm at the t-th period is defined as follows:

$$TE_{it}= E\ [\exp(-\eta_{it}u_i)] \quad \text{where } \eta_{it}=\exp\ [-\eta\ (t-T)] \tag{4.9}$$

4.3.2 Battese and Coelli (1995) Model

Although Battese and Coelli (1992) model allows the efficiencies to vary over time, it has a significant limitation, since the rank ordering of the firms does not change even if there is a change in the efficiency scores over time (Coelli et.al, 2005). Furthermore, the model does not provide any explanation about the "environmental variables" that

[15] σ_u^2 is not equal to the variance of the inefficiency term u, contrarily it is the scale parameter of u. Thus, the estimated parameter γ cannot be interpreted as the proportion of the total variance that is due to inefficiency. For this interpretation Var (γ) is required, see Henningsen (2014).

could affect efficiency levels. To illustrate, the production levels of the farmers with the same amount of land and animals can differentiate from each other based on farmers' age and education level. At this point, age and education are the environmental variables that can affect production levels of the farmers.

Regarding these drawbacks of the Battese and Coelli (1992) model, a new model has been introduced by Battese and Coelli (1995), in which technical inefficiency effects are assumed to be a function of firm-specific variables and time. In this new model, the inefficiency effects are independently distributed as truncations of normal distributions with constant variance similar to the Battese and Coelli (1992) model. On the other hand, the means of the inefficiency effects is a linear function of some observable variables. Therefore, Battese and Coelli (1995) model considers not only time-varying technical inefficiency but also its components.

In the models proposed by Pitt and Lee (1981) and Kalirajan (1981), stochastic frontier production function and technical inefficiencies are estimated without environmental variables in the first stage. In the second stage, these predicted technical inefficiencies are regressed on the environmental variables to identify the reasons for differences in predicted efficiency levels. Although two-stage method was used widely, it has been recognized as an inconsistent method since it assumes the independence of the inefficiencies in the two estimation stages (Coelli, 1996).

The Battese and Coelli (1995) model has contributed to the efficiency literature since it estimates the parameters of the stochastic production frontier and the inefficiency effects equations with environmental variables simultaneously by using MLE. This one-stage estimation procedure does not contradict the independence assumption of inefficiencies and is found to be more successful in providing efficient estimates compared to two-stage estimation (Coelli, 1996).

In the model introduced by Battese and Coelli (1995), the stochastic frontier production function with N firms over T periods is specified as follows:

$$\ln q_{it} = x_{it}'\beta + v_{it} - u_{it} \qquad i = 1, 2 \ldots N, \quad t = 1, 2 \ldots T \tag{4.10}$$

The technical inefficiency effect u_{it} in this stochastic frontier model is assumed to be independently and identically distributed as truncations at zero of N ($z_{it}\delta$, σ_u^2) such as:

$$u_{it} = z_{it}\delta + w_{it} \tag{4.11}$$

where z_{it} is a (1xm) vector of environmental variables accounting for the inefficiency effects, δ is a (mx1) vector of unknown coefficients accounting for marginal effects of these environmental variables on technical inefficiency and w_{it} is a random variable distributed with zero mean and constant variance such as $N(0,\sigma^2)$.

In the model, some assumptions regarding the parameters can be tested based on generalized Likelihood Ratio (LR) statistics (Battese and Coelli, 1995) such as:

H_0: $\gamma = 0 \rightarrow u_i$'s are not stochastic,
H_0: $\gamma = \delta_0 = \delta_1 = \cdots = \delta_k = 0 \rightarrow u_i$'s are absent in the model, i.e., no inefficiency,
H_0: $\delta_1 = \delta_2 = \delta_3 = \cdots = \delta_k = 0 \rightarrow u_i$'s are not a linear function of the environmental variables.

The mean technical efficiency of the i-th firm at the t-th period is defined as follows:

$$TE_{it} = \exp(-u_{it}) = \exp(-z_{it}\delta - w_{it}) \tag{4.12}$$

Both 1992 and 1995 models of Battese and Coelli are not special cases of each other, so using some restrictions on one of these models does not allow us to determine which specification to choose (Coelli, 1996). Moreover, since assuming independence of the terms v_{it} and u_{it} is a simplistic approach, the alternative models considering possible correlation between inefficiency effects and statistical noise terms should be investigated (Battese and Coelli, 1995).

4.3.3 Stochastic Cost Frontiers

All of the aforementioned models and their specifications are related to stochastic production functions. If prices are available and an approach of minimizing costs for the economic agent is reasonable, then stochastic cost functions that give the minimum expenditure needed to produce a given output can be defined. In Figure 4.6, stochastic cost frontier is illustrated together with deterministic cost frontier and observed cost values. At point x_k, the distance between stochastic cost frontier and observed cost value corresponds to the cost inefficiency, whereas the distance between two cost frontiers corresponds to the statistical noise.

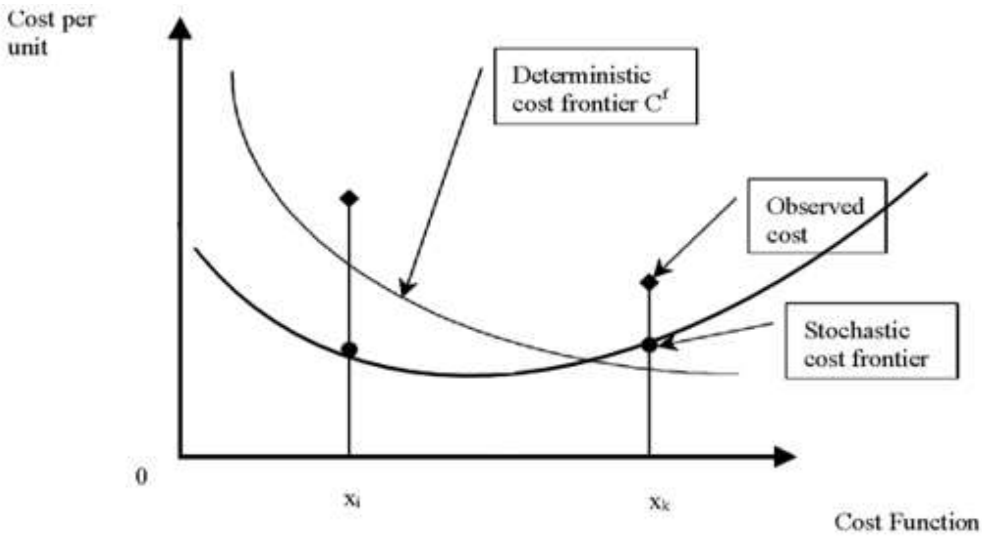

Figure 4.6 Deterministic and stochastic cost frontiers
Source: *Anderson and Kabir (2000, p.23)*

The cost function differs from the production function in some respects: The composite error term for a cost function is equal to $v_{it}+u_{it}$ instead of $v_{it}-u_{it}$ as in the production function. Furthermore, definitions of y and x vectors are different from those in the production function such as:

$$\ln q_{it}= x_{it}'\beta+ v_{it}+u_{it} \tag{4.13}$$

where q_{it} is the cost of production of the i-th firm in the t-th time period, x_{it} is a k*1 vector of (transformations of the) input prices and output of the i-th firm in the t-th time period and β is the vector of the unknown parameters.

In the model v_{it} is the statistical noise term assumed to be independently and identically normally distributed, i.e., $v_i \sim iii$ N(0, σ_v^2). On the other hand, u_{it} is non-negative inefficiency term that defines how far a firm operates above the cost frontier. The u_{it} term is assumed to be independently and identically distributed as N(0, σ_u^2) and independent of the v_{it} term. However, sometimes the interpretation of u_{it} is not so clear, since both technical and allocative inefficiencies may be involved in this term. Thus, if allocative efficiency is assumed, u_{it} is closely related to the cost of technical inefficiency, otherwise it is not (Coelli, 1996).

Similar to the production functions, Battese and Coelli (1992, 1995) model specifications can also be defined for cost functions.

4.4 Energy Demand and Energy Efficiency Measurement by Stochastic Demand Frontier Approach Based on Filippini and Hunt (2011)

As mentioned before, the study by Filippini and Hunt (2011) is the first study that combines input demand function and SFA to measure efficiency in energy use. In their study, Filippini and Hunt (2011) make efficiency estimations by using stochastic frontier models, i.e., pooled model based on Aigner et al. (1977) and the True Random Effects (TRE) model proposed by Greene (2005a, 2005b). By using these models, energy efficiency levels of different countries are obtained, but the determinants of inefficiency are not explained. Although our study is based on Filippini and Hunt (2011), we also aim to account for the reasons for inefficiency besides obtaining the efficiency scores by using another stochastic frontier specification, i.e., Battese and

Coelli (1995) model as in the subsequent studies of Filippini et.al (2014), Otsuka and Goto (2015), Weyman-Jones et.al (2015) and Otsuka (2017, 2018).

Filippini and Hunt (2011) derives economy-wide aggregate energy demand from the demand for energy services such as heating, lighting, cooking, water heating etc. for different sectors such as residential, industrial, transportation etc. Using a combination of energy and capital equipments such as household appliances, insulated walls, cars, machinery, etc., these services can be produced by economic agents in the production process. Following the neoclassical production framework, it is assumed that rational economic agents choose the minimum amount of inputs and the input combination that minimizes the costs to produce certain amount of energy services (cost minimization approach). Thus, these services are produced efficiently at the minimum cost (Filippini and Hunt, 2011). However, it is unlikely that households always produce outputs by minimizing the use of all inputs, or at least one of the inputs such as energy. This situation ultimately leads to inefficiency in energy use, i.e., waste energy[16]. Thus, there is a need to measure how efficiently the energy services are produced, namely, the productive energy efficiency. In this case, energy efficiency can be determined by using Kopp's non-radial input specific efficiency measurement, which considers other inputs, except energy, as fixed.

The study by Filippini and Hunt (2011) aims to measure the level of energy efficiency for a panel of 29 OECD countries over the period from 1978 to 2006. In the study, underlying energy efficiency of i-th country in year t is measured by defining an aggregate energy demand relationship as follows:

$$E_{it}=E\ (P_{it}, Y_{it}, POP_{it}, C_i, A_i, ISH_{it}, SSH_{it}, D_t, EF_{it}) \tag{4.14}$$

where E_{it} is aggregate energy consumption, P_{it} is real price of energy, Y_{it} is gross domestic product, POP_{it} is population, C_i is dummy variable regarding whether a

[16] Waste energy can result from not only producing outputs without minimizing the use of energy but also using an obsolete technology that does not enable households to minimize their energy use.

country has a cold climate or not, A_i is area size of a country, ISH_{it} is the share of value added for industrial sector, and SSH_{it} is the share of value added for service sector. On the other hand, the change in energy consumption over time can result from some other unmeasurable exogenous factors that simultaneously affect all countries, e.g. technical progress, climate change and environmental awareness. Thus, in order to distinguish the effect of these unmeasurable exogenous factors from efficiency, a time trend or a set of time dummy variables can be introduced into the model. D_t is a variable representing underlying energy demand trend to capture all these factors. Finally, EF_{it} is the unobserved level of "underlying energy efficiency" of an economy.

This approach aims to isolate the energy efficiency by explicitly controlling other factors such as price, income, country specific effects, climate effects or some exogenous factors such as technical progress (Filippini and Hunt, 2011).

The energy demand function used here is an input demand function derived from a cost minimizing process (Filippini and Hunt, 2011). Using mainly cost function, one of whose inputs is energy, and Shephard's lemma, energy demand function is obtained[17]. Estimation of a cost function requires information on inputs and input prices. Nonetheless, due to data unavailability on some inputs or inputs' prices, just one input demand function can be estimated as an energy demand function. Therefore, Filippini and Hunt (2015) consider this approach as an ad-hoc one since it does not rely on the theoretical restrictions imposed by the production theory, but it enables us to estimate efficiency from the difference between the actual energy demand function and the stochastic energy demand function. Furthermore, Filippini and Hunt (2011) estimate overall energy efficiency regardless of the distinction between technical and

[17] For further information on this approach, see Weyman-Jones et.al (2016).

allocative energy efficiency[18] since there is no information on energy services produced (outputs) and stocks of household appliances used (capital)[19]

In the study of Filippini and Hunt (2011), economy-wide energy efficiency is approximated by a one-sided non-negative term based on the panel log-log functional Cobb-Douglas form of Equation (4.14) by using SFA as follows:

$$e_{it}=\alpha+\alpha^{p}p_{it}+\alpha^{y}y_{it}+\alpha^{pop}pop_{it}+\alpha^{c}C_{i}+\alpha^{a}a_{i}+\alpha^{\imath}ISH_{it}+\alpha^{s}SSH_{it}+\delta_{t}D_{t}+v_{it}+u_{it} \quad (4.15)$$[20]

The terms v_{it} and u_{it} in Equation (4.15) are related to the composite error term ($v_{it}+u_{it}$).[21] Specifically, v_{it} is a symmetric disturbance term, i.e., stochastic term capturing the effect of noise and it is assumed to be normally distributed. On the other hand, the term u_{it} is the inefficiency term assumed to follow a half-normal distribution.

In Figure 4.7, the baseline energy demand, namely, frontier reflects the demand of the countries that utilize highly efficient equipment and manage production process efficiently. It also gives the minimum amount of energy (E) that is necessary to produce a given level of energy services (Y). On the other hand, the difference between

[18] Here, technical efficiency corresponds to minimizing amounts of inputs used to produce a given level of energy services, whereas allocative efficiency accounts for choosing the combination of inputs that minimize the costs to produce a given level of energy services. For an example of estimation of technical efficiency in electricity use, one can refer to Boogen (2017).

[19] Although there is no information on the stock of household appliances due data unavailability, it can be assumed that the stock of household appliances is proportional to some variables available such as household size. In this way, the influence of the stock of home appliances can be explained, and energy efficiency can be measured by using Kopp's input specific approach. Nonetheless, one should be cautious that it is an implicit assumption. See Otsuka (2017) and Boogen (2017).

[20] In equation 4.15, the variables except those, which are in the form of percentage or dummy, are in the logarithmic form. These logarithmic variables are illustrated by small letters in the equation.

[21] Since energy demand function is derived from a cost minimizing process, the composite error term in SFA is in the form of $v_{it}+u_{it}$, different from the composite error term in the output maximization process i.e. $v_{it}-u_{it}$.

the observed energy demand and this cost-minimizing energy demand gives overall energy inefficiency and the distance from the frontier is explained by inefficiency and /or stochastic term. Thus, according to the position of a country with respect to the frontier, some preliminary comments regarding its level of efficiency can be made.

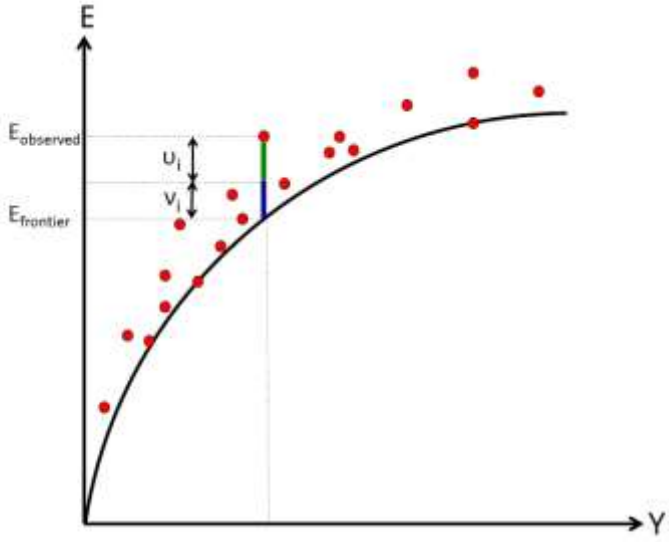

Figure 4.7 Measuring energy efficiency with SFA
Source: *Boogen (2018, s.14)*

In Figure 4.7, the baseline energy demand, namely, frontier reflects the demand of the countries that utilize highly efficient equipment and manage production process efficiently. It also gives the minimum amount of energy (E) that is necessary to produce a given level of energy services (Y). On the other hand, the difference between the observed energy demand and this cost-minimizing energy demand gives overall energy inefficiency and the distance from the frontier is explained by inefficiency and /or stochastic term. Thus, according to the position of a country with respect to the frontier, some preliminary comments regarding its level of efficiency can be made.

Combining all of these definitions and concepts, based on conditional mean of the inefficiency term E (u_{it} / $u_{it}+v_{it}$) suggested by Jondrow et.al (1982), efficiency level of each country (EF_{it}) can be estimated theoretically as follows[22] (Filippini and Hunt, 2011):

$$EF_{it}=\frac{E_{frontier}}{E_{observed}}= \exp(-\hat{u}_{it}) \quad \text{where } \hat{u}_{it} = E\,(u_{it} / u_{it}+v_{it}) \qquad 0<EF_{it} \leq 1 \qquad (4.16)$$

where $E_{observed}$ is the observed energy consumption per capita of i-th country at time t and $E_{frontier}$ is frontier or the minimum energy demand of the i-th country at time t.

While a country on the frontier takes a score of one, i.e., 100% efficiency, a country that is not on the frontier receive a score less than one, i.e., its level of energy efficiency is lower than 100%.

Besides its methodological contributions to efficiency literature, the study of Filippini and Hunt (2011) also proposes crucial implications for policy makers. Undoubtedly, one of its most striking results is that energy intensity, simply the ratio of total energy consumption per unit of GDP, may not always be a good indicator of energy efficiency since it can be influenced by social and economic factors other than pure energy efficiency. Thus, relying on solely energy intensity as a proxy for energy efficiency measures may lead policy makers to take misguided decisions while trying to implement energy efficiency and conservation measures.

Following this study, Filippini and Hunt (2012) also measure residential energy efficiency, and many other studies for different sectors have followed these two studies, which are mentioned in Chapter 3.

[22] Energy efficiency can also be calculated by the term exp ($\hat{u}_{it}$). Nonetheless, its interpretation and the range it takes change. For further information, see Filippini and Hunt (2011).

CHAPTER 5

EMPIRICAL MODEL AND RESULTS

In this chapter, our energy demand frontier model developed and the variables used in the model will be introduced. Then, the empirical results of the study will be evaluated. Findings of the study will highlight the factors that can be attributed to the improvements in efficiency. They will reveal whether Turkey's energy efficiency policy reinforced through legislations and strategy plans has been successful or not. Furthermore, since different characteristics of the provinces can result in different efficiency scores, the findings of the study will provide policy makers invaluable measures to develop some province and region specific strategies.

5.1 Model

Residential electricity demand frontier model built in this analysis is inspired by the studies by Filippini and Hunt (2011, 2012). In our study, we extend the model suggested in the study by Filippini and Hunt (2012) by adding certain variables, i.e., population density and income related dummies. Using this energy demand frontier model, we aim to measure the residential electricity efficiency scores of 81 provinces in Turkey between 2008 and 2015.

We assume that the residential electricity demand function for i-th province in t-th year can be specified as follows:

$$\mathrm{E_{it}}=\mathrm{E}\ (\mathrm{P_{it}},\mathrm{Y_{it}},\ \mathrm{AHS_{it}},\ \mathrm{SH_{it}},\ \mathrm{POPDENS_{it}},\ \mathrm{HDD_{it}},\ \mathrm{CDD_{it}}\ ,\ \mathrm{D_t},\ \mathrm{EF_{it}}) \qquad (5.1)$$

where E_{it} is residential electricity consumption per capita, P_{it} is residential sector's real electricity price, Y_{it} is real income per capita, AHS_{it} is average household size, SH_{it} is share of detached houses within total building stock, $POPDENS_{it}$ is population density, HDD_{it} is heating degree days, and CDD_{it} is cooling degree days. D_t is the time trend that illustrates the impact of technical progress and other unobservable exogenous factors that influence all provinces simultaneously and EF_{it} is the level of underlying residential efficiency in electricity use.

Since the electricity efficiency level EF_{it} cannot be directly observed, this indicator has to be estimated by using SFA. At this point, the minimum level of the residential electricity use to produce any given level of output comprises our "electricity demand frontier". Using the SFA under certain assumptions, we find out whether the deviations from the efficient frontier for each province result from mostly the variables regarding structure of the economy, household and dwelling characteristics, climate, or the inefficient use of electricity. As well as obtaining the efficiency scores of provinces for each year, it is also vital to determine the factors contributing to the inefficient use of residential electricity. Therefore, this study applies the model proposed by Battese and Coelli (1995), in which (in)efficiency levels and their determinants are estimated simultaneously.

Considering the methodology that combines energy demand function with SFA, the efficiency of residential sector in electricity use is approximated by a one-sided non-negative term u_{it} based on the log-log functional form of Equation (5.1) as follows:

$$\begin{aligned} \mathrm{InE}_{it} = {} & \alpha + \alpha^{p}\mathrm{InP}_{it} + \alpha^{y}\,\mathrm{InY}_{it} + \alpha^{ahs}\mathrm{InAHS} + \alpha^{sh}\mathrm{SH}_{it} + \alpha^{popdens}\mathrm{InPOPDENS}_{it} + \alpha^{hdd}\mathrm{InHDD}_{it} \\ & \alpha^{cdd}\mathrm{InCDD}_{it} + \alpha^{dpry*hdd}\,\mathrm{DPRY}_{it} * \mathrm{InHDD}_{it} + \alpha^{dpry*cdd}\,\mathrm{DPRY}_{it} * \mathrm{InCDD}_{it} \\ & + \alpha^{t}D_t + v_{it} + u_{it} \end{aligned} \tag{5.2}$$

Additionally a dummy variable $DPRY_{it}$ is used for the provinces whose real income per capita values are greater than Turkey's average in the relevant year.

The composite error term (v_{it}+ u_{it}) in the model comprises of two terms: the noise term assumed to be v_i~ iii N(0, σ_v^2) and the non-negative inefficiency term u_{it} assumed to be independently distributed as the truncation at zero of the N(μ, σ_u^2). These two terms are assumed to be independent of each other and of all regressors in the electricity demand function.

Given Equation (5.2), efficiency level of each province (EF_{it}) can be estimated by using conditional mean of the inefficiency term E (u_{it} / u_{it}+v_{it}) suggested by Jondrow et.al (1982) as follows:

$$EF_{it}=\frac{E_{frontier}}{E_{observed}}= \exp(-\hat{u}_{it}) \qquad 0<EF_{it} \leq 1 \tag{5.3}$$

where $E_{observed}$ is the observed residential electricity consumption per capita for i-th province at time t and $E_{frontier}$ is frontier or the minimum residential electricity demand per capita of the i-th province at time t. The difference between the observed electricity demand and minimum (cost-minimizing) electricity demand estimated by frontier gives overall residential electricity inefficiency. If a province on the frontier takes a score of one, i.e., 100% efficiency, then a province that is not on the frontier will receive a score less than one, i.e., its efficiency level is lower than 100%.

The studies by Filippini and Hunt (2011, 2012) only focus on obtaining the efficiency scores rather than analyzing the factors affecting the (in)efficiency. On the other hand, in our study mean of inefficiency term μ_{it}, forming inefficiency effects equation is formulated as in the following form:

$$\mu_{it}= \beta+\beta^{weduc}WEDUC_{it}+\beta^{mar}MAR_{it} +\beta^{dillegal}DILLEGAL_{it}+\beta^{marit}MARIT_{it}+\beta^{2009}D_{2009} +\beta^{2010}D_{2010}+ \beta^{2011}D_{2011}+\beta^{2012}D_{2012}+\beta^{2013}D_{2013}+\beta^{2014}D_{2014}+\beta^{2015}D_{2015} \tag{5.4}$$

where $WEDUC_{it}$ is the share of educated women in the population 15 years of age and over, MAR_{it} is the share of married people in the population 15 years of age and over.

DILLEGAL is a dummy variable for provinces whose loss-illegal electricity use rates are greater than Turkey's average in the relevant year. MARIT_{it} is another dummy variable for the maritime provinces. $\mathrm{D}_{2009.....2015}$ are the time dummies accounting for the changes in inefficiency over time. The negative sign of β's indicates a decrease in the inefficiency, i.e., an improvement in the efficiency.

5.2 Data

The current study is the first energy efficiency research on residential electricity consumption of Turkey at the provincial level. The main reason for focusing only on electricity use of residential sector is data availability. Since our research aims to conduct an analysis at the provincial level, it is not possible to find data for other energy resources such as coal and natural gas. Therefore, we focus on electricity use as the source of energy. The study employs a balanced panel of 81 provinces of Turkey over the period 2008-2015. The data set is based on information compiled from various sources. Concentrating specifically on the period of 2008-2015 is due to availability of variables in the model for different years. To illustrate, average household size data are available only for the post-2008 period, whereas the amounts of loss-illegal electricity use obtained by data request are not available for the post-2016 period. For the sake of clarity, each variable used in the residential electricity demand and inefficiency effects equations will be explained individually in terms of its scope and source.

5.2.1 Variables

Residential electricity consumption per capita is represented with E_{it}. Though the actual electricity consumption data for provinces are not available, the data on invoice-based consumption for different sectors (industrial, commercial, residential etc.) at the provincial level can be obtained from TurkStat. Furthermore, we acquire the amounts of loss-illegal electricity consumption of provinces from Turkish Electricity Distribution Corporation (TEDC). Thus, by combining total invoice-based consumption with the amounts of illegal consumption, we aim to converge the actual electricity consumption for each province[23]. Çakmak (2014) also points out the necessity of this kind of approach in his study aiming to forecast future electricity consumption of provinces in Turkey. Since the share of residential electricity consumption in the total electricity consumption is already known from the invoice-based consumption, using this ratio and converging actual electricity consumption, we are able to find the aggregate residential electricity consumption of provinces approximately. Dividing this consumption amount by population of each province, we obtain residential electricity consumption per capita. If the distribution of the illegal electricity use among different sectors such as industrial, residential, agricultural etc. at province level was known, the amounts of illegal electricity use could be distributed to residential sector more accurately. Thus, more precise calculations on actual residential electricity consumption could be made.

Residential sector's real electricity price is represented with $\mathrm{P_{it}}$. Electricity prices in Turkey are determined by EMRA and national tariff scheme has been applied since 2006. Therefore, nominal price of electricity for residential units is the same for all 81 provinces. Residential electricity price data that cover all taxes for residential units can be obtained from TurkStat. On the other hand, these nominal prices are converted into real prices by using Consumer Price Index (CPI) values published by TurkStat for 26 regions of Turkey. For example, to find the real residential electricity price in 2010 the following formula is used: $\text{Real price}^{2010} = \text{Nominal price}^{2010} \text{ x } \frac{\mathrm{CPI}^{2008}}{\mathrm{CPI}^{2010}}$ where base year is 2008. In accordance with demand theory, we expect a negative relationship between

[23] Using the invoice-based consumption data may lead to misleading results as seen in Figure 2.8 and Figure 2.9. The actual consumptions of some provinces in Turkey may be remarkably high though their billed consumptions are low. Neglecting this situation would result in erroneously concluding that these provinces are more efficient in terms of residential electricity use.

electricity price and consumption, namely, an increase in the price will result in a decrease in electricity demand.

Real income per capita is represented with $\mathrm{Y_{it}}$. Nominal GDPs of provinces obtained from TurkStat are converted into real values by using CPIs available for 26 regions of Turkey. For example, to find the real GDP in 2010 the following formula is used: $\text{Real income}^{2010} = \frac{\text{Nominal Income}^{2010}}{\text{CPI}^{2010}}$ x 100. Dividing real income values by the population, we obtain real income per capita of each province. In accordance with demand theory, we expect a positive relationship between real income per capita and electricity consumption, namely, an increase in income will lead to higher amounts of consumption. One reason for such a positive relationship may be that households with higher incomes can afford to buy more electrical appliances or use electricity for the purpose of heating and cooling, so they tend to use more electricity at their homes.

Average household size is represented with $\mathrm{AHS_{it}}$. Average size by provinces is obtained from Address Based Population Registration System (ABPRS) data published by TurkStat. Predicting the relationship between household size and electricity consumption for Turkey is not as straightforward as price and income. In the literature, there are many studies indicating either a positive or a negative relationship. Nonetheless, a negative relationship seems to be more probable. Household members share the same electrical appliances such as refrigerator, television etc. at their homes. Therefore, an increase in the household size can result in a decrease in electricity consumption per household member.

Share of detached houses is represented with $\mathrm{SH_{it}}$. This variable shows the share of detached houses within total building stock that comprises the sum of detached houses and apartments. In the data obtained from TurkStat, the buildings with at most two floors are classified as “detached house” and the buildings with at least three floors are classified as “apartment”. Since detached houses usually have larger floor area compared to the apartments, more electricity may be required to heat or cool these buildings. Thus, the increase in the number of these buildings may also lead to the increase in electricity consumption.

Population density is represented with $\mathrm{POPDENS}_{\mathrm{it}}$. Population density is a measurement of population per unit area. These values by provinces are taken from ABPRS data. We anticipate that increasing population density for a province brings along also increasing electricity consumption.

Heating degree days and cooling degree days are represented with $\mathrm{HDD}_{\mathrm{it}}$ and $\mathrm{CDD}_{\mathrm{it}}$, respectively. The data on heating and cooling degree days are obtained from General Directorate of Meteorology. Eurostat uses the following methodology for the calculation of HDD and CDD, which is also adopted by General Directorate of Meteorology.

HDD expresses the severity of cold in a specific time period taking into consideration outdoor and room temperature, while CDD expresses the severity of heat in a specific time period considering outdoor temperature. They are calculated as follows:

HDD = (18°C - T_m) x d if $T_m \leq$ 15°C (heating threshold)
HDD = 0 if $T_m >$ 15°C

CDD = (T_m - 22°C) x d if $T_m >$ 22°C (cooling threshold)
CDD = 0 if $T_m \leq$ 22°C

where T_m is the daily average outdoor temperature, and d is the number of the days.

Calculations are executed on a daily basis and then extended to months and subsequently to a year. It is important to know the total number of HDD and/or CDD in terms of determining energy necessity for heating and/or cooling of buildings. If the outside temperature is more than 15°C, then heating is unnecessary. On the other hand, if the temperature is over 22°C, then cooling is required. As mentioned before, coal, wood and natural gas are the most commonly used resources for space heating, so we expect a negative relationship between heating degree days and residential electricity consumption per capita. Indeed, we are more interested in revealing whether Turkey uses electricity for cooling or not. Even if there is not a significant relationship considering all provinces of Turkey, we anticipate that provinces with high-income levels use more electricity for cooling.

Dummy variable for income is represented with $\mathrm{DPRY}_{\mathrm{it}}$. This variable takes the value "1" for the provinces whose real income per capita values are higher than the median value for Turkey in the relevant year and "0" otherwise. Mean values are not used because of the outliers. This dummy variable is created to analyze whether income has an important impact on the use of electricity for heating and cooling or not. To illustrate, the prosperous provinces prefer to use air conditioners especially in the summer, and this may affect their residential electricity consumption remarkably. Thus, the contribution of electricity use for cooling to Turkey's overall residential electricity consumption may not be significant, but the case may be different for provinces with high-income levels.

Share of educated women in the population 15 years of age and over is represented with $\mathrm{WEDUC}_{\mathrm{it}}$.Women are the family members who use electricity more compared to other members especially for the housework. On the other hand, educated women are considered to be more conscious about energy efficiency issues such as using energy efficient appliances and environmental problems. Furthermore, since educated women spend their time at work, they use electricity generally off-peak times at nights rather than in the daytime compared to their counterparts spending all of their time at home. In this way, they can benefit from time-of use tariffs and reduce their electricity bills while using electricity more efficiently. To take all these issues into account, we define the variable as the ratio of number of women having high school and university education to total number of population 15 years of age and over. The data on education and population are compiled from TurkStat.

Share of married people in the population 15 years of age and over is represented with $\mathrm{MAR_{it}}$. People who will get married and are already married tend to pay more attention to purchase energy efficient appliances considering their energy labels. Furthermore, they are more cautious about their energy consumption considering their budget. Hence, the increase in the number of married people is expected to lead to an increase in the efficiency. This variable is constructed based on ABPRS data, and it mainly grounds on the share of married people in the total population 15 years of age and over for the relevant years.

Dummy variable for loss-illegal electricity use is represented with $\mathrm{DILLEGAL_{it}}$. Since using loss- illegal use rates directly creates a multicollinearity problem with the variables of education, marriage etc., we prefer to create a dummy variable as an alternative. This dummy variable takes the value "1" for the provinces whose loss-illegal use rates are higher than the median value for Turkey in the relevant year and "0" otherwise. Mean values are not used because of the outliers. This dummy variable is formed to analyze whether the provinces with high loss-illegal use rates are inclined to use residential electricity inefficiently or not. We consider that loss-illegal electricity use is a critical factor that determines inefficient use of residential electricity in certain provinces of Turkey.

Dummy variable for maritime provinces is represented with $\mathrm{MARIT_{it}}$. This variable takes the value "1" for the 28 provinces of Turkey that are maritime and "0" otherwise. Maritime provinces have distinctive characteristics such as high prosperity, high humidity levels and increasing population especially in the summer. All these factors are assumed to affect residential electricity consumption in these provinces remarkably. Undoubtedly, if we had monthly data, we could observe the effects much better.

Table 5.1 summarizes the descriptive statistics on the variables used in the residential electricity demand and inefficiency effects equations. Furthermore, Table 5.2 shows how the means of these variables change by years. To illustrate, the mean of residential electricity consumption per capita in 2009 increased by 1.9% compared to that in 2008, while real income per capita decreased by 5.5% compared to that in 2008. According to Table 5.2, some rough interpretations can also be made on the changing trends in Turkey. Turkey's electricity demand has increased with its increasing population and economic growth over time. On the other hand, residential electricity prices did not follow a particular pattern between 2008 and 2015. Indeed, electricity prices are not determined freely in the market, but by the governmental authority EMRA as mentioned before. Along with increasing income and women's education level, parents have started to have less children and live in apartments rather than detached houses. Additionally, the share of married people in the population has been declining slightly, namely, there has been a rise in the number of single people in the society. Furthermore, it should be noted that climate conditions in Turkey have been changing over time. Turkey experienced cold winters in 2011 and 2015, whereas hot summers in 2010, 2012 and 2014. The change in the means of the variables between 2008 and 2015, based on Table 5.2 are also presented graphically in Figure 5.1. The fluctuations in the means of the variables, electricity price, women's education, heating and cooling degree days are obvious.

Table 5.1

Descriptive statistics

Year	Residential electricity consumption per capita (KWh)	Real electricity price (kuruş/kWh)	Real income per capita (TL)	Average household size	Share of detached houses(%)	Population density (person/km^2)	Heating degree days	Cooling degree days	Share of educated women in population 15 years of age and over (%)	Married people(%)
2008										
Mean	546.65	21.20	6,421	4.32	47.18	113	2,291	359	8.64	63.88
Std.dev.	149.34	0	2,449	1.19	16.60	272	920	324	2.91	4.97
Max	1,067.76	21.20	14,205	8.20	90.80	2,444	4,796	1,614	18.40	70.38
Min	287.56	21.20	2,408	2.90	16.20	12	629	1	2.63	49.17
2009										
Mean	556.85	23.56	6,070	4.29	47.01	114	2,124	263	9.46	63.91
Std.dev.	157.83	0.28	2,180	1.23	16.51	276	821	278	3.06	4.61
Max	1,094.87	24.30	13,230	8.40	90.40	2,486	4,515	1,271	19.34	70.27
Min	329.20	23	2,436	2.90	16.10	11	628	1	3.08	49.62
2010										
Mean	562.16	23.76	6,616	4.17	46.53	116	1,800	413	10.19	63.81
Std.dev.	147.89	0.35	2,243	1.23	16.21	284	720	294	3.13	4.16
Max	1,088.63	24.60	13,992	8.34	89.70	2,551	3,936	1,367	20.10	70.17
Min	349.89	23	3,022	2.84	16.10	10	409	1	3.75	51.16
2011										
Mean	590.24	21.71	7,042	4.07	46.40	118	2,504	283	11.11	63.71
Std.dev.	141.84	0.39	2,506	1.20	16.17	292	884	281	3.18	4.75
Max	1,011.46	22.60	15,116	8.15	89.20	2,622	4,935	1,272	21.02	69.77
Min	354.62	20.90	2,886	2.80	16.10	11	722	1	4.56	46.91
2012										
Mean	598.08	24.24	7,403	3.98	46.19	119	2,257	362	11.62	63.51
Std.dev.	151.29	0.42	2,526	1.16	16.10	297	832	313	3.23	4.65
Max	1,017.03	25.10	15,815	7.89	89.10	2,666	4,708	1,466	21.34	69.05
Min	345.29	23.50	3,198	2.76	15.90	12	824	1	4.92	45.51
2013										
Mean	611.87	24.59	7,780	3.87	45.96	121	2,183	289	12.23	63.49
Std.dev.	156.46	0.44	2,674	1.07	16.03	303	903	286	3.19	4.20
Max	1,136.91	25.40	16,725	7.66	88.60	2,725	4,944	1,294	21.95	68.54
Min	347.54	23.80	3,309	2.73	15.90	11	555	1	5.44	48.39
2014										
Mean	622.38	23.42	8,041	3.77	45.71	123	1,938	350	12.94	63.40
Std.dev.	167.28	0.45	2,759	1.01	15.92	308	838	274	3.30	4.12
Max	1,399.48	24.20	17,038	7.34	87.70	2,767	4,483	1,395	22.70	68.63
Min	396.23	22.40	3,306	2.70	15.70	12	449	1	6.05	48.10
2015										
Mean	632.30	23.05	8,339	3.69	45.44	125	2,196	350	13.82	63.19
Std.dev.	200.66	0.44	2,749	0.95	15.82	314	837	303	3.38	4.08
Max	1,619.21	23.70	17,826	7.04	87.30	2,821	4,774	1,455	23.59	68.20
Min	363.93	22	3,500	2.68	15.50	12	617	1	6.39	47.59

*For avoiding calculation problems, the values of “0” in CDD are replaced by “1”.

Table 5.2

Change in the means of the variables by years (%)

Years	Δ in E	Δ in P	Δ in Y	Δ in AHS	Δ in SH	Δ in POPDENS	Δ in HDD	Δ in CDD	Δ in WEDUC	Δ in MAR
2009	1.9	11.1	-5.5	-0.7	-0.37	1.5	-7.3	-26.7	9.4	0.05
2010	1	0.8	9	-2.9	-1.02	1.6	-15.2	56.9	7.8	-0.17
2011	5	-8.6	6.4	-2.2	-0.28	1.4	39.1	-31.5	9.1	-0.15
2012	1.3	11.6	5.1	-2.4	-0.46	1.3	-9.9	28.0	4.6	-0.31
2013	2.3	1.5	5.1	-2.7	-0.49	1.5	-3.3	-20.2	5.2	-0.04
2014	1.7	-4.7	3.4	-2.5	-0.54	1.3	-11.2	21.2	5.9	-0.15
2015	1.6	-1.6	3.7	-2.3	-0.60	1.4	13.3	0.1	6.8	-0.33

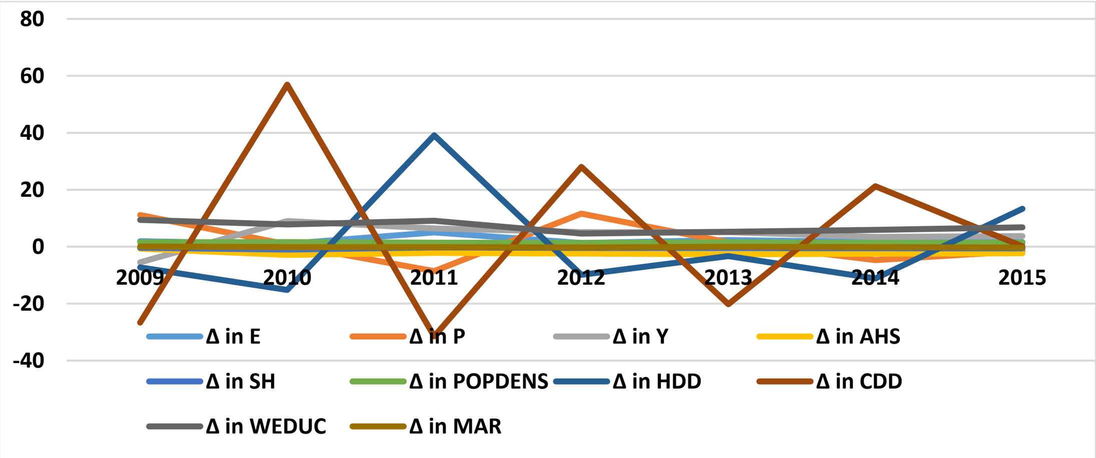

Figure 5.1 Illustration of the change in the means of the variables included in the equations by years (%)

Before starting the analysis, we also examine whether there is a serious correlation among the variables included in both equations or not, which may lead to multicollinearity problem. When Figure 5.2 is examined, it is observed that the correlations among the variables are not so critical[24]. In the figure, positive and negative correlations are displayed in blue and red, respectively. The color intensity and the size of the circle are proportional to the correlations.

[24] The correlation between two variables, if one of them is in the electricity demand equation and the other is in the inefficiency effects equation, does not create a problem for the estimation procedure. In the literature, there are studies using even the same variable in both of the equations such as Otsuka (2017).

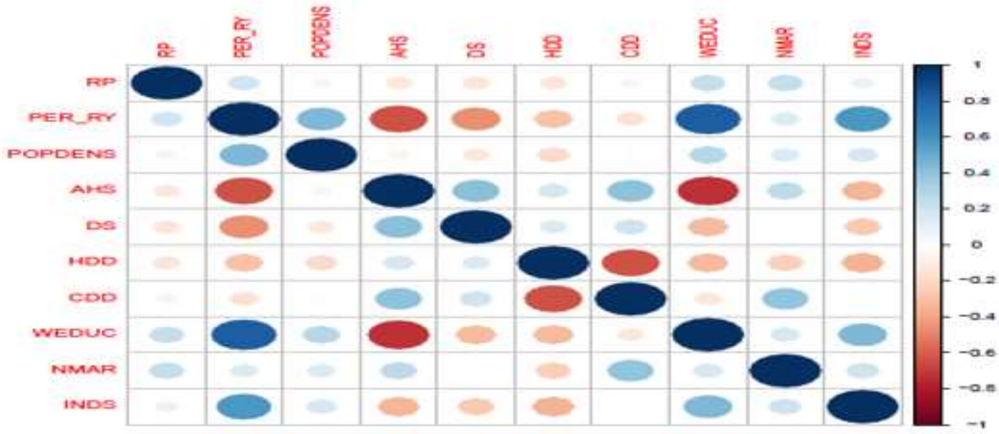

Figure 5.2 Matrix of correlations among the variables included in both equations

5.3 Empirical Results

All of the parameters of the electricity demand and inefficiency effects equations are estimated by means of a package named "Frontier" in R (computer program) written by Coelli and Henningsen in 2013. Estimation and hypothesis testing results are presented in Table 5.3 and Table 5.4, respectively.

Estimation results indicate that most of the parameter estimates for both equations are significant and their signs are compatible with our a priori expectations in general. As mentioned before, the parameter γ lies between zero and one, and it shows the importance of the inefficiency term. If γ is close to zero, there is no inefficiency, and the model is not different from OLS. On the other hand, if it is close to one, deviations from the frontier can be explained by inefficiency. In our model, γ value is approximately equal to 0.89, which implies that the deviations from the frontier can be explained by both the statistical noise term and the inefficiency term, but the contribution of inefficiency is more important. Although z-test also confirms the importance of γ, this test is not valid since γ is bounded by [0,1]; therefore, it cannot have a z-distribution.

Table 5.3

Estimation results

ESTIMATION RESULTS	Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Electricity Demand Equation					
(Intercept)	α	0.5835	0.6324	0.9226	**not significant**
ln(P)	α^{p}	-0.1874	0.1428	-1.3126	**not significant**
ln(Y)	α^{y}	0.1364	0.0378	3.6076	significant ***
ln(AHS)	α^{ahs}	-0.6138	0.0852	-7.2077	significant ***
SH	α^{sh}	0.0019	0.0006	2.9964	significant **
ln(POPDENS)	$\alpha^{popdens}$	0.1200	0.0113	10.5802	significant ***
ln(HDD)	α^{hdd}	-0.0887	0.0322	-2.7564	significant **
ln(CDD)	α^{cdd}	-0.0256	0.0074	-3.4643	significant ***
I(DPRY *ln(HDD))	$\alpha^{dpry*hdd}$	-0.0136	0.0072	-1.89904	significant.
I(DPRY *ln(CDD))	$\alpha^{dpry*cdd}$	0.0268	0.0103	2.6148	significant **
time	α^{t}	-0.0021	0.0035	-0.6172	**not significant**
Inefficiency Effects Equation					
Z_(Intercept)	β	4.8400	0.4049	11.9524	significant ***
Z_WEDUC	β^{weduc}	-0.1052	0.0134	-7.8600	significant ***
Z_MAR	β^{mar}	-0.0745	0.0068	-10.8894	significant ***
Z_DILLEGAL	$\beta^{dillegal}$	0.3087	0.0765	4.0337	significant ***
Z_MARIT	β^{marit}	0.7278	0.0900	8.0896	significant ***
Z_D2009	β^{2009}	0.1679	0.0697	2.4077	significant *
Z_D2010	β^{2010}	0.2185	0.0810	2.6988	significant **
Z_D2011	β^{2011}	0.3653	0.0770	4.7456	significant ***
Z_D2012	β^{2012}	0.3748	0.0926	4.0485	significant ***
Z_D2013	β^{2013}	0.5176	0.0940	5.5090	significant ***
Z_D2014	β^{2014}	0.5471	0.0967	5.6569	significant ***
Z_D2015	β^{2015}	0.7043	0.1094	6.4392	significant ***
Variance Parameters					
gamma	γ	0.887	0.023	38.042	significant ***
sigma square	σ^2	0.078	0.009	8.549	significant ***
sigma square u	σ_u^2	0.069	0.010	7.246	significant ***
sigma square v	σ_v^2	0.009	0.001	7.147	significant ***
sigma	σ	0.279	0.016	17.098	significant ***
sigma u	σ_u	0.263	0.018	14.492	significant ***
sigma v	σ_v	0.094	0.007	14.293	significant ***
lambda square	λ^2	7.850	1.826	4.299	significant ***
lambda	λ	2.802	0.326	8.597	significant ***
log likelihood value		297.55			

Level of significances: "***" at %0.1, "**" at %1, "*" at %5 and "." at %10

Table 5.4

Hypothesis testing results

Null hypothesis to test	Test Statistic	Critical Value*	Decision
H_0: γ**= β=β^{weduc}=β^{mar}=$\beta^{dillegal}$=β^{marit}=β^{2009}=$\beta^{2010}=\cdots=\beta^{2015}$=0	345.07	21.742	Reject H_0
H_0: β^{weduc}=β^{mar}=$\beta^{dillegal}$=β^{marit}=β^{2009}=$\beta^{2010}=\cdots=\beta^{2015}$=0	307.58	19.675	Reject H_0
H_0: β^{2009}=$\beta^{2010}=\cdots=\beta^{2015}$=0	47.513	14.067	Reject H_0

*Critical value of the test statistic at the 5% level of significance.
**All hypotheses are tested based on Generalized Likelihood Ratio Statistics that is defined as $\lambda=-2\ln(L_0-L_1)$ where L_0 and L_1 are the values of the likelihood function for the frontiers model under the null (H_0) and alternative hypothesis (H_1), respectively. Under the null hypothesis, test statistics for the first hypothesis asymptotically follows a mixed chi-square distribution (Kodde and Palm, 1986).

At this point, a likelihood ratio test can be used to check whether there is a significant inefficiency effect in the stochastic frontier model or not. The first hypothesis in Table 5.4, which is rejected at the 5% significance level, points out that stochastic frontier model fits to our data better than OLS. After confirming the existence of inefficiency in the model, another matter of interest is the joint significance of inefficiency determinants. The result of the second hypothesis in Table 5.4 shows that the variables we include in our inefficiency effects equation are statistically significant in explaining inefficiency term. Lastly, third hypothesis in Table 5.4 rejects that inefficiency is time-invariant. To sum up, results of these three hypothesis tests indicate that we should use stochastic frontier approach, inefficiency in electricity use can be accounted by the variables we selected, and the inefficiency varies over time.

The dependent variable and most of the variables in the electricity demand equation are in logarithmic form. This allows us to reduce the scale and to interpret estimated coefficients as elasticities.

Unlike the demand theory, the estimation results indicate that electricity price does not influence residential electricity demand of Turkish provinces. This may result from the fact that the variation in the electricity prices is relatively low across the provinces. Another reason may be that the electricity prices in Turkey are determined by the government, not in the market. Filippini and Zhang (2016) also do not find a statistically significant relationship between energy prices and energy demand when they estimate energy efficiency of Chinese provinces, in which energy prices are relatively low and fully controlled by the government. On the other hand, the estimated long-term[25] income elasticity is approximately 0.14, meaning that if household income increases by 10%, then residential electricity demand will increase by about 1.4%.

There is a significant negative relationship between household size and electricity consumption per capita, namely, if household size increases by 10%, then residential electricity demand will decrease by about 6.1%. This finding is in line with the study of Yohanis et.al (2008) carried for British households, the study of Blázquez et.al (2013) for Spanish households and the study of Boogen (2017) for Portuguese households. This result can be attributed to the household scale economies (Otsuka, 2017). Large families have many electrical appliances at their homes and may seem to consume more electricity. On the other hand, rather than living separately, household members living in the same house share the same appliances such as refrigerator, washing machine, dish washer etc. and so they economize on electricity use. Hence, appliance usage per household member decreases and, therefore, per capita electricity consumption decreases.

The findings suggest that detached houses consume more electricity than apartments. This finding is quite common in the literature, given the examples of Wiesmann et al. (2011) for Portugal, Bedir et al. (2013) for Netherlands, and Kavousian et al. (2013) for the USA. On the other hand, increase in population density results in higher amounts of electricity consumption as expected.

Considering the negative relationship between climate variables and electricity consumption, it is concluded that Turkish households do not use electricity for the

[25] Since this type of studies does not consider the lag of the residential electricity demand in estimating the power demand function, they estimate long-term mean elasticities, not the short-term elasticities (Otsuka, 2017).

purpose of heating and cooling in general. Particularly, this result for HDD is as expected since coal and natural gas are the main sources of space heating at homes. According to Turkish Household Budget Survey 2016, only 2% of Turkish households use electricity for space heating (Aydın, 2018). This finding is also parallel to the study of Otsuka (2017) carried out for Chinese provinces, in which heating demand is met from other resources such as kerosene rather than electricity.

This case for CDD changes when only the provinces with high-income levels are considered. The results indicate that households even with high-income levels do not use electricity for heating. On the other hand, prosperous provinces tend to use electricity for cooling at high temperatures.

The time trend is not statistically significant. Hence, there is no definite positive or negative impact of technical progress and other unobservable exogenous factors that influence all provinces simultaneously in terms of residential electricity consumption.

After evaluating the variables that influence residential electricity demand, we concentrate on the estimation results for the variables that account for inefficient use of residential electricity. The sign of the estimated coefficient of the variable WEDUC is negative as expected. This suggests that as women, who have an important share in residential electricity consumption, become more educated, inefficiency decreases. This may be related to their increasing awareness on the purchase and use of energy efficient appliances, and their environmental consciousness. Furthermore, our analysis reveals that the correlation between the variables of women’s education and income per capita in Turkey is 0.82. Consequently, as women become well-educated, their incomes increase, which can affect their preferences for consumption. To illustrate, they can afford to buy more energy efficient appliances, which are generally more expensive in the market. On the other hand, Carlsson-Kanyama and Linde´n (2007) reveal that Swedish women are slightly more inclined to save energy at home and change their attitudes based on the policies implemented such as the change in electricity prices. Furthermore, Gaspar and Antunes (2011)[26] find out that women consider energy consumption related characteristics of an electrical appliance in their purchasing decision and they search more for information on energy efficiency class. Contrarily, men pay more attention to the number of functions, the accessories and the technological innovation provided by an appliance purchased. On the other hand, there are many studies in the literature revealing that highly educated people tend to make energy efficiency improvements given the examples of Poortinga et al. (2004) for Netherlands and Mills and Schleich (2012) for 10 EU countries and Norway. This improvement most probably results from their increasing levels of income and awareness. Indeed, Mills and Schleich (2012) suggest that education level has a strong positive impact on household energy-efficient technology adoption and households' energy conservation practices. Thus, female education stands out an important factor for decreasing residential electricity consumption and promoting efficiency.

The negative relationship between marriage rate and inefficiency is also in accord with our a priori expectation. This result implies that the increase in the number of married people brings along increasing efficiency in electricity use at homes. This finding is similar to the study by Trotta (2018), in which the factors affecting energy-saving behavior and energy efficiency investments of British households are analyzed. Trotta (2018) infers that being married positively affects households' energy-saving behavior, the purchase of energy efficient appliances and energy efficient retrofits. Even people tend to continue their energy-saving habits when their marriages ended.

With characteristics of being a peninsula and having high loss-illegal electricity use rates, Turkey differs from many other countries. The estimation results indicate that these two variables are responsible for increasing inefficiency at the residential sector. The maritime provinces of Turkey generally have high-income levels as a result of industrialization, summer tourism or trade etc. They are also exposed to high temperature and humidity rates. Our electricity demand equation also indicates that the

[26] The data in the study are based on the responses collected from the qualitative interviews made with households living in Ireland, Germany, Portugal, Greece, Poland, Spain and Italy.

provinces with high-income levels have a tendency for cooling by electricity in the summertime. Furthermore, with the arrival of summerhouse vacationists and tourists, population in these provinces increases remarkably during summers. Consequently, all these factors may lead to more electricity consumption and increasing inefficiency in electricity use in these maritime provinces.

Illegal electricity use is one of the reasons for increasing inefficiency. The citizens living in the provinces having high loss-illegal electricity use tend to consume more electricity for agricultural irrigation, greenhouse heating or residential use, which increases inefficient use of electricity. In his study searching socio-economic drivers of electricity theft in Turkey, Yurtseven (2015) deduces that income and education are two important factors for decreasing illegal electricity use. On the other hand, increasing electricity prices and rural population, climate conditions leading to consume more electricity, and lower risk of being caught induce illegal electricity use in Turkey.

Lastly, estimated coefficients of the year dummies are positive and statistically significant. This implies that efficiency level of each year is lower than that of 2008. This finding suggests that inefficient use of electricity at the residential sector has not improved over time, and efficiency policies implemented by the authorities after 2007 seem to not have a significant impact on improving residential energy efficiency.

Table 5.5 summarizes certain descriptive statistics on efficiency scores of Turkey between 2008 and 2015. Accordingly, the level of efficiency in residential electricity use decreases from 2008 to 2012, then it starts to improve after 2012 and continues to rise until 2014, and decreases in 2015 again. Indeed, average efficiency level declines by 2.37% from 2008 to 2015. On the other hand, 8-year mean energy efficiency score of Turkey is approximately 0.83. This suggests that Turkish households have an average electricity saving potential of 17%, which reaches its highest level in 2008 and the lowest in 2012. Furthermore, the gap between the most and the least efficient province in the relevant year has increased over time i.e., this difference which was 0.604 has increased by 22% to 0.739 in 2015.

Table 5.5

Certain descriptive statistics on efficiency levels by years

Year	Mean	Δ in Mean (%)	Maximum	Minimum	Max-Min	Standard deviation
2008	0.845	------	0.977	0.373	0.604	0.158
2009	0.831	-1.64	0.976	0.305	0.671	0.168
2010	0.834	0.33	0.977	0.263	0.714	0.168
2011	0.816	-2.14	0.966	0.310	0.656	0.167
2012	0.813	-0.35	0.969	0.339	0.629	0.170
2013	0.819	0.68	0.970	0.309	0.660	0.176
2014	0.828	1.15	0.972	0.270	0.702	0.174
2015	0.825	-0.38	0.979	0.240	0.739	0.183
2008-2015	**0.827**	**-2.37**				

After commenting on the estimation results of the electricity demand and inefficiency effects equations, we can concentrate on province-based results. As mentioned before, energy intensity indicators are frequently used to explain energy efficiency by policy makers and researchers. Nonetheless, using energy intensity as a proxy for energy efficiency does not always give accurate results since energy intensity may be influenced by factors other than energy efficiency. Furthermore, if energy intensity were a good proxy for energy efficiency, we would expect high and positive correlation between the rankings of the energy intensity measures and the estimated energy efficiency scores across the provinces. In Appendix A, comparison of the rankings of provinces based on estimated efficiency scores and energy intensity values[27] between 2008 and 2015 are given, and the Spearman correlation coefficient between these ranks is calculated as 0.498. This result suggests that there is a positive relationship between energy efficiency and energy intensity ranks. However, it is not a strong relationship. This implies that residential electricity use per capita is not a

[27] In our study, "residential energy use per capita", which is suggested by IEA (1995) as an energy intensity indicator for residential sector, is used for measuring energy intensity.

sufficient measure to account for efficiency in residential electricity use. Hence, using this indicator can lead policy makers to take wrong decisions.

Table 5.6 classifies the provinces based on their average efficiency scores between 2008 and 2015. Furthermore, Figure 5.3 presents regional distribution of the inefficient and efficient provinces on the map.

Table 5.6

Classification of provinces based on their average efficiency levels over the period 2008-2015

Estimated Efficiency Levels	Category	# of provinces	Member Provinces									
Below 78%	Most inefficient	20	Ağrı	Antalya	Artvin	Batman	Bingöl	Bitlis	Diyarbakır	Erzurum	Giresun	Hakkâri
			Iğdır	Mardin	Muğla	Muş	Rize	Siirt	Sinop	Şanlıurfa	Şırnak	Van
From 78 % to 90%	Moderately inefficient	20	Adana	Bayburt	Trabzon	Aydın	Kastamonu	Bartın	Yalova	Mersin	İzmir	Samsun
			Kars	Kilis	Hatay	Edirne	Malatya	Ordu	Zonguldak	Kırklareli	Sakarya	Balıkesir
From 90% to 94%	Moderately efficient	25	Adıyaman	A.karahisar	Aksaray	Amasya	Ardahan	Bolu	Bursa	Çanakkale	Çorum	Düzce
			Elazığ	Erzincan	G.antep	G.hane	İstanbul	K.Maraş	Karabük	Kırşehir	Konya	N.şehir
			Niğde	Sivas	Tekirdağ	Tokat	Tunceli					
Above 94%	Most efficient	16	Ankara	Bilecik	Burdur	Çankırı	Denizli	Eskişehir	Isparta	Karaman	Kayseri	Kırıkkale
			Kocaeli	Kütahya	Manisa	Osmaniye	Uşak	Yozgat				

Most inefficient provinces: Their average values of estimated efficiency are lower than the first quartile estimated efficiency.

Moderately inefficient provinces: Their average values of estimated efficiency are between the first quartile and median estimated efficiency.

Moderately efficient provinces: Their average values of estimated efficiency are between the median and upper quartile estimated efficiency.

Efficient provinces: Their average values of estimated efficiency are higher than the upper quartile estimated efficiency.

Figure 5.3 Illustration of provinces based on their average efficiency levels over the period 2008-2015

As seen from Table 5.6, almost half of the provinces in Turkey fall into the “inefficienct province” category. Moreover, out of these 40 provinces, half of them are categorized as “the most inefficient”, the other half are as “moderately inefficient”. Most inefficient provinces have average efficiency levels lower than 78%, whereas moderately efficient ones have average efficiency levels between 78% and 90%. Furthermore, among 20 provinces that are classified as “the most inefficient provinces, 11 have average efficiency levels lower than 70%. Efficiencies of these 11 provinces range between 36% and 64%.

According to the analysis results, the most inefficient province in Turkey between 2008 and 2015 is Hakkari with its 36% efficiency level, which implies that it could have used 64 percent less electricity to produce the same amount of energy services. As seen from Figure 5.3, inefficient provinces are mostly concentrated on the eastern part of Turkey or they are in the coasts. This is not a surprising result since our model already suggests that having high loss-illegal use rate and located in the coastal area affect inefficiency in residential electricity use of provinces.

When 41 provinces that are classified into the “efficient” category are examined, out of these provinces, 25 of them are categorized as “moderately efficient” and 16 of them are categorized as “the most efficient”. Furthermore, moderately efficient provinces have average efficiency levels that vary between 90% and 94%, whereas the most efficient ones have average efficiency levels above 94%.

In this category, Bilecik stands out as “the most efficient province” of Turkey with its 96% efficiency level between 2008 and 2015. This finding implies that Bilecik could have used only 4 percent less electricity to produce the same amount of energy services.

In Table 5.7 and Figure 5.4, the most and the least efficient five provinces between 2008 and 2015 are analyzed in detail. The average efficiency scores of the most efficient provinces are at least 15 percent more than Turkey’s average, whereas the average efficiency scores of the most inefficient provinces are at least 50 percent less than Turkey’s average. The efficient provinces are the ones, in which women are highly educated, the number of married people is high and illegal electricity use is quite low. Contrarily, inefficient provinces are the ones, in which the rates of educated women and married people are low compared to Turkey’s average, but their illegal electricity use is quite above Turkey’s average. To illustrate, the average illegal electricity use rate in Hakkari is 332% more than Turkey’s average.

Table 5.7

The characteristics of the most and the least efficient provinces

Province	Average Efficiency	Efficiency Rank	Rate of Efficiency over Turkey’s Average (%)	Rate of Educated Women over Turkey’s Average (%)	Rate of Married People over Turkey’s Average (%)	Rate of Loss-Illegal Use over Turkey’s Average (%)	Maritime or not
Bilecik	0.968	1	16.8	10.3	0.64	-73.3	0
Kütahya	0.966	2	16.6	-8.2	7.05	-64.05	0
Burdur	0.965	3	16.5	6.6	7.13	-53.11	0
Kocaeli	0.960	4	15.9	31.1	4.23	-63.95	1
Denizli	0.959	5	15.8	17.2	6.87	-65.5	0
D.bakır	0.383	77	-53.7	-27.3	-11.31	326.71	0
Mardin	0.371	78	-55.3	-39.8	-13.58	373.43	0
Şırnak	0.366	79	-55.8	-57.7	-19.29	362.69	0
Ş.urfa	0.365	80	-56.0	-54.7	-8.67	299.98	0
Hakkari	0.364	81	-56.1	-38.0	-24.06	332.6	0

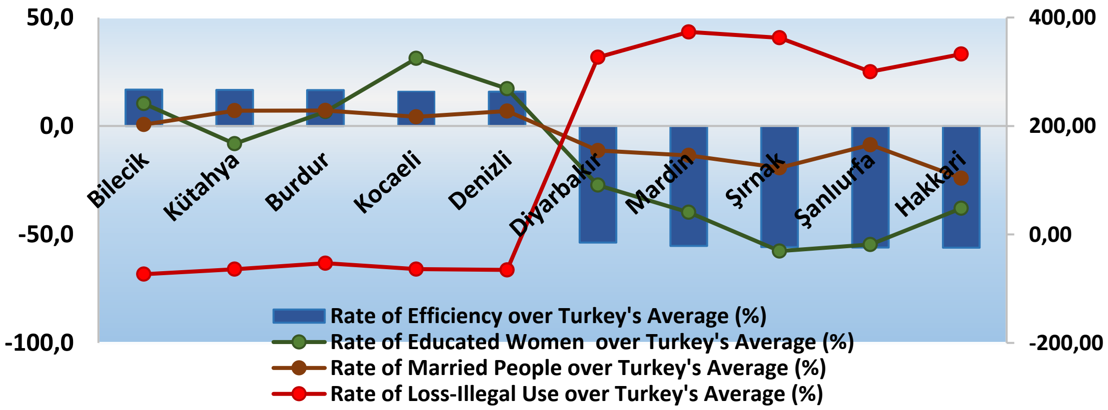

Figure 5.4 Illustration of characteristics of the most and the least efficient provinces

CHAPTER 6

CONCLUSION

This study analyzes residential electricity demand of Turkey over the period 2008-2015. Furthermore, it investigates inefficiencies in residential electricity use of provinces and tries to reveal the factors leading to this inefficiency. The main reason for focusing only on electricity use of residential sector is due to data availability. Since this research aims to conduct an analysis at the provincial level, and it is not possible to find data for other energy resources such as coal and natural gas, only electricity is used as a source of energy in the study. Furthermore, concentrating specifically on the period of 2008-2015 is related to availability of data relation to the variables in the model for different years. Methodologically, this study follows the study by Filippini and Hunt (2011, 2012) and estimates both residential electricity demand and inefficiency effects equations simultaneously based on the model proposed by Battese and Coelli (1995).

The empirical results indicate that higher income, living at detached houses and inhabiting in densely populated provinces are the factors that account for increasing electricity consumption at the dwellings. On the other hand, as household size increases, electricity consumption per capita decreases. This finding is attributed to the household scale economies. Since family members living in the same house share the common electrical appliances, the household appliance usage per household member decreases, and therefore, per capita electricity consumption decreases. Considering the impact of the climate conditions on residential electricity consumption, it is concluded that although Turkish households do not use electricity for heating and cooling in general, provinces with high-income levels tend to use electricity for cooling. Based on the estimated efficiency scores, 8-year mean energy efficiency of Turkey is found to be approximately 0.83. This suggests that on average Turkey could have used 17% less electricity to produce the same amount of energy services between 2008 and 2015.

In other words, Turkish households have an average electricity saving potential of 17% in the study period.

The results of the inefficiency effects equation reveal that being a well-educated woman and being married have a positive impact on improving residential efficiency. Contrarily, provinces with higher loss-illegal use rates and being located in the coastal area use electricity more inefficiently. Furthermore, the results imply that there has not been an improvement in the inefficient use of electricity at the residential sector over time despite the efficiency policies implemented by the authorities after 2007.

Findings of our analysis based on factors determining the inefficiency in electricity use lead to important policy implications. They emphasize the importance of women's education in attaining the goal of energy efficiency in the residential sector with the argument that as women become more educated, their awareness on the purchase of energy efficient appliances and environmental problems increases. The results[28] suggest that if the share of educated women in the population increases by 10%, average efficiency level in residential electricity use improves approximately by 1% in Turkey. Provinces, whose efficiency scores increase at most as women's education levels increase, are Trabzon, Rize, Erzurum, Antalya and Bingöl. Indeed, such results can be a guide while determining the province-based policies to struggle with inefficiency.

The findings of the survey carried out by Turkish Residential Energy Efficiency Financing Facility (TuREEFF) also point out the significance of women's being well-educated. TuREEFF (2016) concludes that gender is an important factor for energy efficiency, and the range of energy efficiency practices adopted by women is wider than by men. According to this survey, in Turkey women are generally the ones who make purchasing decisions on home appliances even if they do not have their own income. Men are more likely to obey their wives' preferences although they are the ones who generally pay for the home appliances. The survey also suggests that women

[28] To obtain marginal effect of education on the efficiency estimates of provinces, "margEff" argument in R was used.

and men with higher income and education levels consider that energy saving is essential for the protection of environment, whereas those with lower income and education levels associate energy saving with reducing bills. On the other hand, the survey conducted in the scope of “Enerji Hanım” project, where the housewives constitute 79% of the people included in the survey, reveals that more than 70% of people are unconscious of energy class of their electrical appliances (Evaluation Results of Enerji Hanım Survey, n.d.). This indicates that introducing energy labelling as a regulation is not sufficient itself. Public awareness should be also raised to promote this regulation.

Another important regulation that interests residential sector is that households can select to be included in one-term tariff or three-term tariffs. In one-term tariff, electricity use is priced by the same tariff throughout the day. On the other hand, in the three-term tariffs, day is divided into three periods such as daytime (06:00-17:00), peak time (17:00-22:00) and night (22:00-06:00). The electricity use in each period is priced differently. To illustrate; the electricity tariff at night is the cheapest, so households can shift their consumption to night and economize on their electricity consumption. In this respect, three term tariffs can be more appropriate for working women. Although there is a conventional belief in the society that using electrical appliances such as dishwashers and washing machines at nights is more economical, three-term tariffs are only available for consumers with smart meters. The ones with mechanic meters cannot benefit from this advantageous tariff if they do not demand from the electricity distribution company at their region to change their meter.

These examples of regulations i.e., energy labelling and three-term tariffs, indicate that scope and benefits of all regulations should be introduced to the public in more detail. Otherwise, they may not be as effective as expected by the policy makers since people are unaware or unconscious of these regulations.

In conclusion, existence of well-educated women plays a critical role in improving residential energy efficiency. Thus, the policies especially targeting women can be effective in promoting residential energy efficiency. Moreover, all regulations and policies should also be promoted by means of the informational and educational campaigns, programs or public service announcements to raise public awareness.

Another important policy that can improve residential electricity efficiency is to reduce illegal electricity use especially in the eastern part of Turkey. In the provinces where illegal electricity use is highly common, this situation leads people to use electricity in the different sectors such as industry, dwellings, agriculture inefficiently. If people consider having lower risk of being caught, and even if they are caught, the punishments are not dissuasive, they will not abandon this “ingrained habit” voluntarily. Furthermore, as long as EMRA applies the same electricity prices to all provinces and the cost of lost electricity is reflected to the consumers who pay their electricity bills regularly, illegal electricity use will continue to be a burden on these consumers. This kind of approach, in which the cost of illegal electricity use is reflected to the consumers by means of higher prices, is criticized as it restrains electricity distribution companies for searching a solution to this problem (Aydın, 2016). Therefore, policy makers should develop more effective policies and provide legal arrangements to struggle illegal electricity use. They should also examine broadly the socio-economic reasons, which lead people to use electricity illegally.

Yurtseven (2015) proposes implementing social tariffs as an alternative solution to this problem. In this way, a reduced tariff can be determined for the vulnerable consumers by considering their purchasing power and social capital levels, and this may deter poor people from illegal electricity use. Another suggestion of Yurtseven (2015) is the use of increasing block tariffs method in case that identification of vulnerable consumers is difficult. In line with international standards, first 100 kWh of electricity per month, that is essential for maintaining basic life necessities, can be offered to these consumers at very low prices or even free of charge. On the other hand, the revenue loss resulting from this mechanism can be compensated in the following blocks by higher tariffs. This kind of support mechanisms may seem to be costly at first glance, but the cost of illegal electricity use to the operation of electricity system may be far more than that. Furthermore, research and development projects on reducing loss-illegal electricity use designed by electricity distribution companies or researchers should be promoted vigorously.

Last suggestion to policy makers is that after conducting efficiency analyses, efficiency goals can be set or certain incentives can be given to the efficient provinces. This type of policy may encourage the inefficient provinces to use electricity more efficiently to benefit from these incentives.

As mentioned before, our study is the first attempt to measure residential energy efficiency at the provincial level by a frontier method. It proposes a new approach to policy makers in measuring efficiency in residential electricity use rather than using simply energy intensity indicators. Nonetheless, this study is restricted to electricity consumption as data for the other sources (natural gas, coal etc.) are not available at provincial level. In case of high quality and detailed energy data at the provincial level are collected, our analysis can be expanded for many different sectors by regional studies. If it is possible to reach data about the ownership of electrical appliances, which are important in terms of residential electricity consumption, similar analyses in Boogen (2017) can be done, and our results can be improved. Lastly, if monthly or seasonal residential electricity consumption data are available, the impact of climate conditions on residential electricity consumption and (in) efficiency in electricity use can be analyzed in more detail.

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APPENDICES

A. COMPARISON OF THE RANKINGS OF PROVINCES BASED ON ESTIMATED EFFICIENCY SCORES AND ENERGY INTENSITY VALUES BETWEEN 2008 AND 2015

Provinces	2008-2015 Average Efficiency	2008-2015 Average Energy Intensity	Efficiency Rank	Energy Intensity Rank
Bilecik	0.9676	483.006	1	21
Kütahya	0.9660	440.067	2	7
Burdur	0.9654	488.641	3	23
Kocaeli	0.9605	621.644	4	54
Denizli	0.9594	581.589	5	46
Kırıkkale	0.9592	507.786	6	30
Manisa	0.9582	571.660	7	43
Uşak	0.9560	513.361	8	34
Ankara	0.9549	706.153	9	67
Osmaniye	0.9534	485.370	10	22
Kayseri	0.9531	511.203	11	33
Yozgat	0.9516	411.350	12	3
Isparta	0.9501	532.544	13	38
Çankırı	0.9501	456.224	14	13
Eskişehir	0.9467	599.204	15	50
Karaman	0.9455	466.713	16	19
Adıyaman	0.9431	370.990	17	1
Erzincan	0.9427	458.838	18	17
Konya	0.9416	492.604	19	25
Kahramanmaraş	0.9395	406.592	20	2
Afyonkarahisar	0.9388	463.153	21	18
İstanbul	0.9382	825.517	22	74
Çanakkale	0.9378	598.905	23	49
Tokat	0.9377	458.002	24	16
Kırşehir	0.9352	505.988	25	29
Niğde	0.9347	452.051	26	12
Bursa	0.9344	627.643	27	56
Gaziantep	0.9329	473.289	28	20
Çorum	0.9322	492.129	29	24
Sivas	0.9321	445.272	30	9
Aksaray	0.9311	451.645	31	11
Bolu	0.9283	552.205	32	40
Karabük	0.9254	554.565	33	41
Elazığ	0.9245	456.346	34	14
Gümüşhane	0.9217	448.431	35	10
Tekirdağ	0.9191	648.353	36	58
Amasya	0.9177	574.422	37	45

(continued)

Provinces	2008-2015 Average Efficiency	2008-2015 Average Energy Intensity	Efficiency Rank	Energy Intensity Rank
Nevşehir	0.9144	547.588	38	39
Düzce	0.9092	566.077	39	42
Ardahan	0.9054	437.073	40	6
Tunceli	0.9048	442.162	41	8
Balıkesir	0.8868	661.122	42	62
Sakarya	0.8845	622.059	43	55
Kırklareli	0.8800	667.334	44	63
Zonguldak	0.8794	603.559	45	52
Ordu	0.8741	574.238	46	44
Malatya	0.8732	509.951	47	32
Edirne	0.8669	685.469	48	65
Hatay	0.8662	589.296	49	48
Kilis	0.8657	526.682	50	36
Kars	0.8541	424.093	51	5
Samsun	0.8502	611.286	52	53
İzmir	0.8438	919.148	53	77
Mersin	0.8363	717.640	54	68
Yalova	0.8297	794.091	55	73
Bartın	0.8214	581.966	56	47
Kastamonu	0.8067	530.106	57	37
Aydın	0.7937	764.992	58	71
Trabzon	0.7764	738.343	59	69
Bayburt	0.7763	508.315	60	31
Adana	0.7762	699.934	61	66
Erzurum	0.7712	502.366	62	28
Antalya	0.7661	904.474	63	76
Iğdır	0.7652	497.136	64	26
Bingöl	0.7587	421.430	65	4
Rize	0.7583	685.147	66	64
Giresun	0.7467	653.102	67	60
Sinop	0.7100	660.947	68	61
Muğla	0.7009	924.487	69	78
Artvin	0.6983	649.665	70	59
Siirt	0.6363	457.113	71	15
Bitlis	0.5994	522.246	72	35
Muş	0.5911	499.958	73	27
Ağrı	0.5036	600.999	74	51
Van	0.4988	642.380	75	57
Batman	0.3928	870.910	76	75
Diyarbakır	0.3835	956.269	77	79
Mardin	0.3707	1001.932	78	81
Şırnak	0.3661	790.263	79	72
Şanlıurfa	0.3645	959.470	80	80
Hakkari	0.3636	739.184	81	70

*Residential electricity use per capita (kWh) is taken as an indicator for energy intensity.

**A rank of 81 for energy efficiency represents the least efficient province, whereas a rank of 1 represents the most efficient province. A rank of 81 for energy intensity represents the most energy intensive province while a rank of 1 represents the least energy intensive province.

B. TURKISH SUMMARY / TÜRKÇE ÖZET

Şüphesiz elektriğin icadı insanlık tarihinin en önemli yeniliklerinden biridir. Hayatın bir parçası haline gelen elektriğin olmadığı bir yaşam dahi hayal edilememektedir. Birkaç saat için dahi yaşanacak bir kesinti durumu, farklı sektörlerdeki tüm ekonomik aktiveleri olumsuz yönde etkileyerek tahminlerin ötesinde ekonomik ve sosyal maliyetlere sebep olacaktır. Bu nedenle, elektriğin yeterli ve kesintisiz arzı özellikle sürdürülebilir sosyal ve ekonomik büyümeyi hedefleyen ülkeler için kritik önem arz etmektedir.

Uluslararası Enerji Ajansı (2019) verilerine göre, küresel elektrik enerjisi talebi 2018 yılında 2017 yılına göre %4'lük bir artış göstererek artış eğilimine devam etmiştir. Elektrik talebinde görülen bu artış, toplam enerji talebinin iki katı kadar olup, 2010 yılından itibaren en yüksek artış hızına ulaşmıştır. Yine ajans verilerine göre, 2018 yılında dünya enerji talebinin %45'i yenilenebilir enerji ile nükleer kaynaklardan sağlanmıştır. Öte yandan, kömür ve doğalgaz santralleri, elektrik üretimine önemli ölçüde katkıda bulunmaya devam etmişlerdir. Kömür ve doğalgaz santrallerinin elektrik üretimindeki payları sırasıyla %38 ve %23 olarak gerçekleşmiş olup, elektrik üretiminden kaynaklanan sera gazı salımları ise, enerji kaynaklı salımların %38'ini oluşturmuştur. Söz konusu rakamların da işaret ettiği üzere, kısıtlı kaynaklar ile artan elektrik talebini karşılamak ve bunu sera gazı salım hedefleri ile çelişmeksizin gerçekleştirmek bir nevi sorun teşkil etmektedir.

Dünyada olduğu gibi, ülkemizde de elektrik tüketimi yıllara göre artan bir eğilim göstermektedir. Ekonomik büyüme, sanayileşme ve artan nüfusun da etkisiyle, Türkiye'nin elektrik tüketimi zamanla önemli ölçüde artmıştır. Türkiye İstatistik Kurumu (TÜİK) verilerine göre, 2007 yılına kıyasla 2017 yılında elektrik tüketimi %60'lık bir artış göstermiştir. 2017 elektrik üretim verilerine bakıldığında ise, üretimde en büyük payı sırasıyla %33 ve % 37 ile kömür ve doğalgaz santralleri almıştır. Öte yandan, toplam elektrik tüketiminin sektörel bazda dağılımına bakıldığında, bu alanda sırasıyla %47 ve %22'lik paylar ile sanayi ve konut sektörleri ön plana çıkmaktadır. Artan talebi karşılamanın yanı sıra Türkiye, diğer önemli sorunlarla da başa çıkmaya çalışmaktadır. Elektrik üretiminde temel kaynak olma özelliği gösteren doğalgazda 2017 yılında %99'lara varan dışa bağımlılık bu sorunların başını çekmektedir (EMRA, 2018b). Ayrıca, doğal gaz arzının büyük bir kısmının yıllardır belli ülkelerden karşılanıyor olması bu ülkelerle yaşanacak siyasi bir kriz durumunda arz güvenliği için büyük bir tehdit oluşturmaktadır. Doğalgazda görülen ciddi oranlarda dışa bağımlılığın yanı sıra, enerji kaynaklı sera gazı salımlarının artışı, Türkiye'nin mücadele ettiği bir diğer sorundur. TÜİK (2019) verilerine göre sera gazı salımı 2017 yılı için 526,3 tona ulaşmış olup, enerji sektörünün toplam salımlardaki payı ise %72 olarak gerçekleşmiştir. 1990 ile kıyaslandığında 2017 yılında sera gazı salımları %140,1'lik bir artış göstermiş olup, sera gazı salımlarında görülen bu çarpıcı artış Türkiye'yi, enerji üretim politikalarını tekrar gözden geçirmeye itmektedir. Bu sorunun çözümü için yenilenebilir enerji kaynakları ilk alternatif olarak akıllara gelse de, bu kaynakların önemli ölçüde iklim koşullarına bağımlı olmaları yeterli ve kesintisiz enerji arzını olumsuz yönde etkilemektedir. Bu noktada, "Enerji Etkinliği" bir diğer önemli alternatif olarak ön plana çıkmaktadır.

Aynı çıktı ya da hizmeti elde etmek için daha az enerji kullanımı şeklinde tanımlansa da enerji etkinliği, ülkelere bundan çok daha fazlasını sunmaktadır. Doğru enerji etkinliği politikaları, en hızlı ve en az maliyetle birçok ülke için ekonomik büyümenin sürdürülmesi, salımların azaltılması ve enerji arzının sağlanmasında önemli bir rol oynamaktadır. Molina (2014), ABD için 2009-2012 döneminde enerji etkinliği programlarının maliyet ve maliyet etkinliğini inceleyen çalışmasında, enerji etkinliğinin, yeni bir üretim santrali inşa etmek gibi farklı elektrik üretim seçenekleri ile kıyaslandığında en düşük maliyetli kaynak olduğu sonucuna varmıştır. Uluslararası Enerji Ajansı (t.y), 2000 yılından beri süregelen enerji etkinliği iyileştirmeleri olmamış olsaydı tüm dünyada 2016 yılında %12 daha fazla enerji tüketileceğini belirtmektedir. Bu miktar, Avrupa Birliği'nin toplam enerji gereksinimine karşılık gelmektedir.

Türkiye de diğer birçok dünya ülkesi gibi son yıllarda enerji tüketiminde iyileştirmeler yapmak adına son derece önemli adımlar atmıştır. Bu yöndeki en somut adımlar 2007 yılında Enerji Verimliği Kanununun yürürlüğe girmesi ile atılmış olup o tarihten bu yana söz konusu Kanunu diğer birçok düzenleme izlemiştir. Bu düzenlemeler ile sanayi, ulaşım gibi birçok farklı sektöre ilişkin etkinlik hedefleri belirlenmiş olup, konut sektörü de düzenlemelere tabi tutulan sektörlerden olmuştur. Elektrikli aletlerde enerji etiketlenmesi ile binalara enerji kimlik belgesine sahip olunması şartı getirilmesi konuta ilişkin önemli düzenlemelerdendir.

TÜİK verilerine göre 2017 yılında, hane halkları sayısı 22 milyonu geçmiş olup, konutun toplam elektrik tüketimindeki payı ise yaklaşık %22 olarak gerçekleşmiştir. Bu demek oluyor ki, 2017 yılında Türkiye'de üretilen elektriğin yaklaşık dörtte biri evlerde tüketilmiştir. Bu sebeple, en fazla elektrik tüketen sektörlerden biri olan konut sektörüne ilişkin tüketim kalıplarını incelemek ve konutlarda elektrik tüketimine ilişkin etkinsizliğin nedenlerini belirlemek önem arz etmektedir. Öte yandan, konuta yönelik mevzuata ilişkin düzenlemelerin elektrik tüketimi ile etkinliğe olan etkilerini ortaya koymak geleceğe yönelik politikalar için ayrıca önem taşımaktadır.

Etkinliğin sayısal olarak ölçülmesine gelindiğinde ise, günümüzde etkinlik ölçümü çalışmaları bankacılık, tarım, sağlık gibi birçok farklı sektörde kullanılmaktadır. Enerji ise başlı başına akademik ve deneysel çalışmaların yoğunlaştığı önemli sektörlerden birisidir. Özellikle son zamanlarda enerji alanında, elektrik ve doğalgaz dağıtım şirketlerinin etkinlikleri ile farklı sektörlerde enerji kullanımına ilişkin etkinlik çalışmaları ön plana çıkmaktadır. Enerji kullanımına ilişkin olarak, Filippini ve Hunt tarafından 2011 yılında yayımlanan ve OECD ülkeleri için enerji kullanımına ilişkin etkinlik ölçümü yapan akademik çalışma, yazında büyük ilgi uyandırmıştır. Söz konusu çalışma, girdi talep fonksiyonu ile stokastik sınır yaklaşımını birleştirerek birincil enerji kullanımındaki enerji etkinliğini ölçen ilk çalışma olması yönüyle, bu çalışmada olduğu gibi bu alanda yapılan birçok çalışma için de ilham kaynağı olmuştur.

Konutta elektrik kullanımında etkinliğe odaklanan akademik çalışmaların ülkemiz için oldukça kısıtlı olduğu göz önünde bulundurulursa, çalışmamız bu alanda ilk olma özelliğini göstermektedir. Bilindiği kadarıyla, Türkiye'de konutta enerji etkinliğini ve bu etkin(siz)liğin nedenlerini il bazında sınır yöntemi ile inceleyen başka bir akademik çalışma bulunmamaktadır. Yapılan çalışmaların büyük bir kısmı Türkiye'nin de içinde olduğu OECD ya da Avrupa Birliği ülkeleri arasındaki karşılaştırmalara odaklanmakta olup bu çalışmalarda diğer bir sınır yöntemi olan Veri Zarflama Analizi (VZA) kullanıldığı görülmektedir. Söz konusu çalışmaların genel olarak toplulaştırılmış (genel) enerji etkinliği ya da sanayide enerji etkinliği ölçümlerine odaklandıkları anlaşılmaktadır. Birçok değişken için veri olmaması nedeniyle il bazında genel ya da sanayiye ilişkin çalışmalar oldukça azdır. Köne ve Büke (2012), Özkara ve Atak (2015) ve İlhan (2015) çalışmaları bu alanda yapılmış nadir çalışmalardandır.

Konutta enerji etkinliği çalışmalarına gelindiğinde ise bu alanda il bazında yapılmış bir çalışma bulunmamakta olup, Morgül (2014) ve Aydın (2018) çalışmaları, ülkemiz için konutta elektrik tüketimindeki etkinlik yazınına katkı sağlamaktadır. Morgül, 500'den fazla katılımcının dâhil olduğu ve 2013-2014 yıllarında tamamlanan anket çalışması sonucunda, çapraz tablolama yöntemi ile hane halklarının tüketim kalıpları ile enerji etkinliğine ilişkin tutumlarına ilişkin belli çıkarımlarda bulunmaktadır. Anket sonuçlarına göre, elektrikli ev aletlerine ilişkin enerji etiketlemesi, pik saat kullanımı, akıllı sayaç uygulaması, bekleme konumunda tüketim[29] hakkında bilgi sahibi olunması ile elektrikli su ısıtıcısı, çay ya da kahve makinelerinin etkin kullanımı, konutta elektrik tüketiminde etkinliğin iyileştirilmesinde önemli rol oynamaktadır.

Morgül (2014) çalışması, konutta elektrik kullanımında etkinlik konusuna genel bir yaklaşım sunmakla beraber, daha önce de belirtildiği üzere VZA ya da Stokastik Sınır Analizi (SSA) gibi yöntemler kullanılmaksızın çapraz tablolama yöntemi ile belli çıkarımlarda bulunmaktadır. Diğer bir çalışma olan Aydın (2018), enerji etiketlemesi uygulamasının konutta enerji etkinliğine olan etkilerini incelemekte olup, çalışma

[29] İngilizce "standby consumption" öbeğinden çevrilmiştir.

TÜİK tarafından yapılmış Hanehalkı Bütçe Anketlerini kullanarak En Küçük Kareler yöntemi ile tahminlerde bulunmaktadır. Çalışma sonunda, enerji etiketlemesi uygulamasının konutta elektrik enerjisi tüketiminin azaltılmasına katkı sağladığı sonucuna varılmaktadır.

Çalışmamız, söz konusu iki çalışmadan farklı olarak konutta etkinlik konusunu sınır yöntemi kullanarak il bazında ele almakta olup, aynı zamanda bu anlamda Türkiye için yapılmış ilk çalışma olma özelliğini göstermektedir. Çalışmamızın amaçlarından biri, 2008-2015 yılları için standart talep değişkenlerinin yanı sıra konut ve hanehalkına ilişkin değişkenleri de ekleyerek Türkiye'de konutta elektrik talep fonksiyonunu tahmin etmektir. Çalışmamızın bir diğer amacı ise, il bazında enerji etkinliği skorlarını belirleyerek etkin(siz)liğin olası nedenlerini ortaya koymaktır. Bu amaçla, Battese ve Coelli (1995) tarafından önerilen "etkinsizlik" etkileri modeli temel alınarak aynı anda hem konut elektrik talebi hem de etkinsizlik etkileri denklemleri tahmin edilmektedir. Elde edilen etkinlik skorlarına göre iller belli kategorilere ayrılarak tüketimde etkinsizliğin nedenleri ayrıca tartışılmaktadır.

Çalışma kapsamında kullanılan yöntem detaylandırılmadan önce yazında sıklıkla birbirlerinin yerine kullanılan verimlilik ve etkinlik kavramlarını birbirinden ayırt etmek gerekmektedir. Etkinlik, temelde gözlenen girdi ve çıktı değerlerinin en uygun girdi ve çıktı değerlerine oranını ifade etmektedir. Çıktıyı en çoklaştıran yaklaşım açısından bakıldığında, belli teknoloji ve girdiler ile en çok çıktıyı elde edebilme, maliyeti en aza indirme yaklaşımı ile bakıldığında ise, en az girdi bileşimi ile belli bir çıktıyı elde edebilme kabiliyeti olarak tanımlanmaktadır. Öte yandan, verimlilik, üretim sürecinde kullanılan girdilerin çıktılara oranını ifade etmektedir. Yazında söz konusu kavramları, daha önce de belirtildiği üzere birbiri yerine kullanma eğilimi olsa da, bu iki kavram tam olarak aynı şeyler değildir. Çünkü etkinlik artışı daima verimlilik artışını beraberinde getirmemektedir (Coelli ve diğerleri, 2005). Temelde, etkinlik verimliliğin belirleyicilerinden yalnızca biri olarak değerlendirilmekte ve ekonomik bir aktör için etkinliği sağlamadan verimliliği sağlamak mümkün görünmemektedir. Ayrıca, etkinlik kısa dönemli bir olgu iken, verimlilik uzun dönemlidir (Odyakmaz, 2009).

Farklı etkinlik türleri bulunmakla beraber bunlardan teknik etkinlik, çıktıyı en çoklaştıran yaklaşım ile bakıldığında belli teknoloji ve girdiler ile en çok çıktıyı elde edebilmeyi ifade etmekte; fiyat bilgilerinin de olması durumunda diğer bir etkinlik türü olan "tahsis etkinliği" ise, belli miktarda çıktıyı en az maliyetle üretmeye olanak sağlayan girdi bileşimini seçmeyi ifade etmektedir. Bu iki etkinlik türünün birleşimi ise, "üretim etkinliğini" oluşturmaktadır. Kopp (1981) tarafından üretim etkinliği, bir ekonomik birimin en çok çıktıyı en az maliyetle üretebilme kabiliyeti olarak tanımlanmaktadır.

Etkinlik ölçümüne gelindiğinde ise, yazında girdi odaklı ve çıktı odaklı olmak üzere iki farklı etkinlik ölçüm yaklaşımı bulunmaktadır. Girdi odaklı yaklaşımlar, çıktı miktarını değiştirmeksizin orantılı olarak girdi miktarlarının ne kadar azaltılabileceğine odaklanırken, çıktı odaklı yaklaşımlar ise, üretim sürecinde kullanılacak girdi miktarlarını değiştirmeksizin çıktı miktarının ne kadar arttırılabileceğine odaklanmaktadır (Coelli ve diğerleri, 2005). Çalışmamız, hane halklarının belli miktardaki ısınma, aydınlatma vs. şeklindeki enerji hizmetlerini en az miktarda elektrik kullanarak üretmede ne kadar başarılı olduklarını ölçmesi yönüyle girdi odaklı bir yaklaşım örneğidir.

Etkinlik kavramı, türleri ve etkinlik ölçümüne ilişkin farklı kavramlar tanıtıldıktan sonra önemli bir soru belirmektedir: "Etkinlik Nasıl Ölçülecektir?". Bu noktada, Farrell (1957) tarafından önerilen radyal ölçüm ile ve Kopp (1981) tarafından önerilen radyal olmayan ölçüm yöntemleri ön plana çıkmaktadır.

Farrell'in etkinlik ölçümü, çoklu faktörlerin teknik ve tahsis etkinliğini tek bir indekste birleştirmektedir. Bu yaklaşımda, üretim sürecinde kullanılan tüm girdilerin etkinlikleri değerlendirmeye alınır ve gözlemlenen etkinlik iyileştirmesinin tüm girdi miktarlarının orantılı olarak azalması ile gerçekleştiği varsayılır. Yine bu yaklaşım kapsamında, girdi uzaklığı, üretim ve maliyet fonksiyonları kullanılarak etkinlik ölçümü yapılır. Öte yandan, Farrell'in etkinlik ölçümü her bir faktörün üretim etkinliğine olan bireysel katkısını ayrı ayrı ortaya koymaktan uzaktır. Ayrıca, tek bir girdiye ilişkin etkinliğin ölçülmek istendiği ya da gerçek hayatta bazı girdilerin sabit ya da yarı sabit olduğu durumlar sıklıkla olabilir. Bu durumda, Farrell'in bu yaklaşımı yerine, Kopp (1981) tarafından önerilen radyal olmayan etkinlik ölçümü kullanılabilir. Bu yaklaşımı enerji etkinliği açısından ele aldığımızda, üretim sürecine dâhil edilen girdilerden fiziki sermayeyi (elektrikli ev aletleri vs.) sabit varsayarak belli bir enerji hizmetini (ısınma, aydınlatma vs.) üretmek için gerekli olacak en az elektrik enerjisi kullanımı tahmin edilebilir. Gözlemlenen elektrik kullanımından da hareketle bir ekonomik birimin elektrik kullanımdaki etkinliği ölçülebilir. Kopp yaklaşımı temelinde, girdi gereksinim[30], Shephard uzaklık ve girdi talep fonksiyonları kullanılarak etkinlik ölçümü yapılabilir. Çalışmamızda, enerji hizmetlerinin üretilmesinde kullanılan girdilerden yalnızca elektrik kullanımındaki etkinliğin ölçülmesi amaçlandığından Kopp'un önermiş olduğu yaklaşımdan yararlanılacaktır.

Radyal ya da radyal olmayan yaklaşımlardan hangisinin kullanılacağına karar verildikten sonra, enerji etkinliğini ölçmek için hangi yöntem ve fonksiyonun kullanılacağına karar vermek de bir diğer önemli husustur. Söz konusu yöntemler, sınır veya sınır olmayan, parametrik veya parametrik olmayan, stokastik veya deterministik yöntemler şeklinde farklılaşmaktadır. Söz konusu yöntemler, sırf kolay hesaplanması nedeniyle tercih edilen ancak etkinlikle alakalı olmayan değişiklikleri de içermesi nedeniyle aslında enerji etkinliği için her zaman iyi bir gösterge olmayan "Enerji/ Gayri Safi Yurt İçi Hâsıla" oranına bir tür alternatif sunmaktadır. Detaylarına, birbirlerine göre avantaj ve dezavantajlarına değinilecek bu yöntemlerden parametrik olmayan VZA ve parametrik SSA, enerji etkinliği ölçümlerinde en çok kullanılan iki yöntem olarak karşımıza çıkmaktadır.

Günümüzde birçok araştırmacı tarafından farklı alanlarda sıklıkla kullanılan parametrik olmayan ve deterministik yöntemlerden VZA Charnes, Cooper ve Rhodes

[30] İngilizce "input requirement function" öbeğinden çevrilmiştir

(1978) tarafından Farrell (1957) çalışmasından yola çıkılarak önerilmiş ve doğrusal programlama yöntemlerini kullanan matematiksel bir yöntemdir. Bu yöntem ile temelde homojen olduğu varsayılan karar verici birimlerin, diğer benzer birimlere kıyasla belli miktarda girdi ile belli bir çıktıyı elde etmede ne kadar etkin oldukları ölçülür (Mardani, 2017). VZA'nın da içinde olduğu deterministik modeller, sınırdan sapmaların tamamını dışsal şoklar, ölçüm hataları ve yanlış fonksiyonel form belirleme vs. gibi durumları göz önünde bulundurmaksızın "etkinsizlik "olarak belirlemeleri yönüyle yazında tartışmalı bir yaklaşım olarak değerlendirilmektedir (Førsund ve diğerleri, 1980).

VZA ya da SSA yöntemlerinden hangisinin hangi durumlarda kullanılacağı ise bazı etkenlere bağlıdır (Sarafidis, 2002). Sınıra ilişkin fonksiyonel formu belirlemenin olmadığı ve/veya ihmal edilen değişkenlerin sonuçları etkileyeceğinin düşünüldüğü durumlarda SSA'yı kullanmak daha doğru bir yaklaşım olacaktır. Ayrıca, SSA yönteminde istatistiksel testler yardımıyla modelde yer alan değişkenlerin önemli olup olmadıklarına karar vermek ve böylelikle modeli belirlemek mümkündür. Öte yandan, modelde yer alan değişkenler arasında ciddi bir korelasyon sorunu varsa ve/veya sınıra ilişkin doğru fonksiyonel formu belirlemek kolay değil ise SSA yerine VZA'ı seçmek daha makul olacaktır.

SSA ile etkinlik ölçümünde kullanılabilecek fonksiyonları girdi gereksinim, Shephard uzaklık ve girdi talep fonksiyonları şeklinde sınıflandırmak mümkündür. Girdi gereksinim ve Shephard uzaklık fonksiyonları yalnızca teknik etkinlik hakkında bilgi verirken, girdi talep fonksiyonları teknik ve tahsis etkinliğini içeren üretim etkinliği hakkında bilgi vermektedir. Girdi miktarlarını kullanan girdi talep fonksiyonları, koşullu stokastik sınır fonksiyonu maliyeti en aza indirme sürecinden türetileceğinden girdi fiyatları bilgisini de gerektirmektedir (Filippini ve Hunt, 2015). Öte yandan, enerji etkinliğinin ölçümünde kullanılan enerji gereksinim ve Shephard enerji uzaklık fonksiyonları "içselleştirme" probleminden muzdariptir (Kipouros, 2017). Bu sebeple, çalışmamızda Filippini ve Hunt (2011) çalışmasında olduğu gibi enerji girdi talep fonksiyonu temelinde bir tür maliyeti en aza indirme mantığıyla etkinlik ölçümüne gidilecektir.

Deterministik sınır modellere dışsal şoklar, ölçüm hataları ve yanlış fonksiyonel form belirleme gibi durumları kapsayacak şekilde bir istatistiksel hata teriminin ilave edilmesi ile bu modeller stokastik sınır modellerine dönüşmektedir. Stokastik sınır modelleri Aigner ve diğerleri (1977) ile Meeusen ve van den Broeck (1977) tarafından birbirlerinden bağımsız ve eş zamanlı olarak önerilmiş olup, modelin yatay kesit üretim fonksiyonuna ilişkin formu şu şekildedir:

$$\text{In } q_i = x_i{'}\beta + v_i - u_i \qquad (1)$$

q_i: i'ninci firmanın üretim miktarıdır.

x_i : i'ninci firmanın girdi miktarlarının logaritmasını içeren vektördür.

β: bilinmeyen parametreler vektörüdür.

u_i : negatif olmayan yarı normal dağıldığı varsayılan etkinsizlik terimidir.

v_i: kasıtlı olmaksızın ihmal edilen değişken durumu, ölçüm ya da örnekleme hataları ve yanlış fonksiyonel form belirleme gibi durumlarla ilişkili istatistiksel hata terimidir.

$v_i \sim$ iii $N(0, \sigma_v^2)$ ve $u_i \sim$iii $N'(0, \sigma_u^2)$ şeklinde dağılmakta olup, birbirlerinden ve modelde yer alan açıklayıcı değişkenlerden bağımsızdırlar.

Modelde yer alan hata terimlerine ilişkin varsayımlar da dikkate alındığında, birleşik hata teriminin $\varepsilon_i = v_i - u_i$ nin asimetrik yani, E $(\varepsilon_i) \leq 0$ olması nedeniyle etkinsizlik teriminin, En Küçük Kareler Yöntemi (EKK) ile bu birleşik hata teriminden ayrıştırılması mümkün olmamaktadır (Çakmak ve diğerleri, 2008). Öte yandan, EKK yönteminin kullanılması, eğim katsayıları için tutarlı tahmin ediciler sağlarken, kesişim katsayısı için yanlı tahmin ediciler üretmektedir. Bu nedenle, EKK yöntemi etkin(siz)lik hesaplaması için uygun bir yöntem olmayıp, Maksimum Olabilirlik Tahmini (MOT), asimptotik olarak etkinlik ölçümünde EKK ve Düzeltilmiş EKK yöntemlerinden daha etkin bir yöntem olmaktadır (Coelli ve diğerleri, 2005).

MOT yöntemi ile bu şekilde birleşik hata terimi tahmin edilebilmekte, sonrasında Jondrow ve diğerleri (1982) tarafından önerilen koşullu olasılık dağılımı yaklaşımı temelli bir yöntem ile denklem (2)'de olduğu gibi teknik etkinlik düzeyleri (TE) tahmin edilebilmektedir.

$$TE_i = \frac{q_i}{\exp(x_i'\beta + v_i)} = \frac{\exp(x_i'\beta + v_i - u_i)}{\exp(x_i'\beta + v_i)} = \exp(-u_i) \qquad 0 < TE_i < 1 \qquad (2)$$

Modelin ilk halinde etkinsizlik terimleri yarı normal dağılsa da zamanla kesikli normal, üstel ve gamma şeklinde dağılımlar da önerilmiştir. Araştırmacıların hangi dağılımla çalışacağı tezin yöntem kısmında da açıklandığı üzere belli etkenlere bağlıdır. Yine stokastik sınır fonksiyonunun fonksiyonel formunu belirlemek bir diğer önemli konudur. Cobb-Douglas, translog, ikinci dereceden, genelleştirilmiş Leontief vs. şeklinde birçok farklı biçim olsa da her bir seçimin kendi içinde dezavantajlarının olabileceğinin araştırmacılarca farkında olunması gerekmektedir.

İlk halinde yatay kesit veriye uygulanmış olan SSA, Pitt ve Lee (1981) tarafından panel veri setine genişletilmiştir. Yine etkinsizliğin zamana göre değişmediğini varsayan ilk modeller yerine Cornwell ve diğerleri (1990), Kumbhakar (1990), Battese ve Coelli, (1992,1995), Lee ve Schmidt (1993) tarafından etkinsizliğin zamanla değişimine izin veren modeller geliştirilmiştir.

Battese ve Coelli (1992) tarafından geliştirilen model, etkinlik değerlerinin zamanla değişmesine izin vermesine karşın önemli bir dezavantaja sahiptir. Bu model ile firmaların etkinlik değerleri zamanla değişse bile etkinlik sıralamaları değişmemektedir. Ayrıca bu model, etkinlik düzeylerini etkileyen "çevresel faktörler" hakkında herhangi bir bilgi de içermemektedir.

Battese ve Coelli (1992) modelindeki bu eksikliklerden ötürü, Battese ve Coelli (1995) modeli geliştirilmiş olup bu yeni model ile etkinsizlik etkilerinin belli değişkenler ve zamanın bir fonksiyonu olduğu varsayılmaktadır. Söz konusu yeni model ile hem etkin(siz)liklerin zamana göre değişmesine izin verilmekte hem de etkinsizliğin nedenleri açıklanmaktadır.

Battese ve Coelli (1992, 1995) modelleri üretim fonksiyonlarının yanı sıra maliyet fonksiyonlarına da uygulanabilmektedir.

Çalışmamızda, Türkiye için konutta elektrik talebi, Filippini ve Hunt (2011, 2012) çalışmaları ışığında modellenmiştir. Bu çalışmalarda, enerji diğer girdilerle birlikte üretim faktörü olarak ele alınmakta ve SSA kullanılarak enerji etkinliği tahmin edilmektedir. Belli bir çıktı düzeyini elde etmek için gerekli olacak en az enerji miktarı "enerji talep sınırını" oluşturmakta ve sınırdan pozitif sapmalar "enerji kullanımında etkinsizliğe" tekabül etmektedir.

2008-2015 yılları için konutta elektrik enerjisi talebinin i'nci il ve t'inci yıl için aşağıdaki gibi olduğu varsayılmaktadır:

$$\mathrm{E_{it}}=\mathrm{E}\ (\mathrm{P_{it}}, \mathrm{Y_{it}}, \mathrm{AHS_{it}}, \mathrm{SH_{it}}, \mathrm{POPDENS_{it}}, \mathrm{HDD_{it}}, \mathrm{CDD_{it}}, \mathrm{D_t}, \mathrm{EF_{it}}) \qquad (3)$$

$\mathrm{E_{it}}$ kişi başı konutta elektrik tüketimi, $\mathrm{P_{it}}$ konut reel elektrik fiyatı, $\mathrm{Y_{it}}$ kişi başı reel gelir, $\mathrm{AHS_{it}}$ ortalama hanehalkı büyüklüğü, $\mathrm{SH_{it}}$ müstakil konutların toplam konut stokundaki payı, $\mathrm{POPDENS_{it}}$ nüfus yoğunluğu, $\mathrm{HDD_{it}}$ ısıtma gün dereceleri ve $\mathrm{CDD_{it}}$ soğutma gün dereceleridir. $\mathrm{D_t}$ tüm illeri aynı anda etkileyen teknik gelişme ya da diğer gözlenemeyen dışsal faktörleri temsil etmekte olup, $\mathrm{EF_{it}}$ ise elektrik kullanımında etkinlik düzeyini göstermektedir.

Enerji talep fonksiyonu ile SSA analizini birleştiren yönteme göre, konutların elektrik tüketimlerine ilişkin etkinlik düzeylerine, denklem (3)'ün logaritmik fonksiyonunu temel alan, tek taraflı ve negatif olmayan $\mathrm{u_{it}}$ terimi ile şu şekilde yakınsanabilmektedir:

$$lnE_{it}=\alpha+\alpha^{p}lnP_{it}+\alpha^{y}lnY_{it}+\alpha^{ahs}lnAHS+\alpha^{sh}SH_{it}+\alpha^{popdens}lnPOPDENS_{it}+\alpha^{hdd}lnHDD_{it}$$
$$\alpha^{cdd}lnCDD_{it}+\alpha^{dpry*hdd}DPRY_{it}*lnHDD_{it}+\alpha^{dpry*cdd}DPRY_{it}*lnCDD_{it}$$
$$+\alpha^{t}D_{t}+v_{it}+u_{it} \qquad (4)$$

$DPRY_{it}$ ilgili yıl için Türkiye ortalamasından daha yüksek kişi başı reel gelire sahip olan iller için “1” değerini alan bir kukla değişkendir.

Her bir ile ilişkin etkinlik düzeyi (EF_{it}) ise, Jondrow ve diğerleri (1982)’nin önerdiği üzere etkinsizlik teriminin koşullu ortalaması E (u_{it} / u_{it}+v_{it}) kullanılarak aşağıdaki gibi hesaplanmaktadır:

$$EF_{it}=\frac{E_{frontier}}{E_{observed}}=\exp(-\hat{u}_{it}) \qquad \hat{u}_{it}=E(u_{it}/u_{it}+v_{it}) \qquad (5)$$

$E_{observed}$ t yılında i’nci ilde konutta kişi başına gözlemlenen tüketilen elektrik miktarı iken, $E_{frontier}$ ise, sınır ya da konutta kişi başına tüketilen minimum elektrik miktarını temsil etmektedir. Bu iki değişken arasındaki oran, konutta elektrik tüketimine ilişkin etkinliği vermekte olup, bu değer %100 etkin iller için “1”, etkinliği %100’den düşük illerde birden küçük değerler almaktadır.

Yalnızca etkinlik skorlarını elde etmeye odaklanan Filippini ve Hunt (2011, 2012) çalışmalarından farklı olarak çalışmamızda illerin 2008-2015 yıllarına ilişkin etkinlik skorlarının yanı sıra etkinsizliğin nedenlerini açıklamayı amaçlayan “etkinsizlik etkileri “denklemi aşağıdaki gibi yazılabilmektedir:

$$\mu_{it}=\beta+\beta^{weduc}WEDUC_{it}+\beta^{mar}MAR_{it}+\beta^{dillegal}DILLEGAL_{it}+\beta^{marit}MARIT_{it}+\beta^{2009}D_{2009}$$
$$+\beta^{2010}D_{2010}+\beta^{2011}D_{2011}+\beta^{2012}D_{2012}+\beta^{2013}D_{2013}+\beta^{2014}D_{2014}+\beta^{2015}D_{2015} \qquad (6)$$

$WEDUC_{it}$ 15 yaş ve üstü nüfusta eğitim düzeyi yüksek kadınların payı ve MAR_{it} ise 15 yaş ve üstü nüfusta evli insanların payıdır. DILLEGAL ilgili yıl için elektrik kayıp kaçak oranı Türkiye ortalamasından yüksek olan iller için “1” değerini alan ve $MARIT_{it}$ ise denize kıyısı olan iller için “1” değerini alan kukla değişkenlerdir. $D_{2009.....2015}$ ise etkinsizlikte zamana göre görülebilecek değişiklikleri açıklamak üzere oluşturulan kukla değişkenlerdir. Negatif β'lar etkinsizlikte azalma olduğunu bir başka deyişle, etkinlikte iyileşme olduğunu göstermektedir.

Çalışmada kullanılan değişkenlere ilişkin veriler, birçok farklı kaynaktan derlenmiş olup, il bazında konutta diğer enerji kaynaklarının yani, doğalgaz, kömür vs. tüketimine ilişkin verilerin olmaması nedeniyle enerji türü olarak yalnızca elektriğe odaklanılmıştır. Yine değişkenlere ilişkin verilerin, farklı yıllar için elde edilebilmesi nedeniyle çalışmada özel olarak 2008-2015 dönemine odaklanılmıştır.

Stokastik sınır modelini oluşturan elektrik talep ve etkinsizlik etkileri denklemlerine ilişkin tüm parametreler, R istatiksel bilgisayar programı kullanılarak Coelli ve Henningsen tarafından 2013 yılında geliştirilen "Frontier" paketi aracılığıyla tahmin edilmiştir.

Ampirik sonuçlar yüksek gelirin, müstakil konutlarda yaşamanın ve nüfus yoğunluğu fazla olan illerde ikamet etmenin artan elektrik tüketimi ile sonuçlandığına işaret etmektedir. Öte yandan, hane halkı büyüklüğü artıkça konutta elektrik tüketimi azalmaktadır. Söz konusu sonuçlar, Türkiye'de konutlarda genel olarak ısınma ve soğutma amacı ile elektrik kullanılmadığını gösterse de gelir düzeyi yüksek illerin soğutma amaçlı elektrik tüketimine yönelmekte olduğu görülmektedir. Tahmin edilen etkinlik rakamlarına göre, ülkemizin 8 yıllık etkinlik ortalaması yaklaşık 0,83'tür. Bu rakam, 2008-2015 döneminde Türkiye'de konutlarda aynı çıktıyı elde edebilmek için %17 daha az elektrik kullanılabileceğini göstermektedir. Bir başka deyişle, söz konusu zaman diliminde hane halkları elektrik tüketiminde yaklaşık %17'lik bir tasarruf potansiyeline sahiptir.

Diğer taraftan, etkinsizliğin nedenlerini açıklamayı amaçlayan etkinsizlik etkileri denklemi sonuçlarına göre, kadınların eğitim düzeyinin artması ile evli çift sayısının artması bir ilde tüketimde etkinliğin artmasına katkı sağlamaktadır. Öte yandan, kayıp kaçak elektrik tüketimin fazla olduğu iller ile deniz kıyısında konumlanmış illerde elektriğin daha etkinsiz kullanıldığı sonucuna varılmıştır. Ayrıca, illerin konutta etkinsiz elektrik kullanımlarında zamanla bir iyileşmenin olmadığı görülmekte olup, bu durum özellikle 2007 sonrasında birçok sektör için benimsenen verimlilik politikalarının konutta istenilen sonuca ulaşmadığı şeklinde yorumlanmaktadır. Çalışmanın sonuç kısmında ise, etkinsizlik etkileri denkleminden elde edilen sonuçlar ışığında politika üreticilere bazı önerilerde bulunulmaktadır.

Tahmin edilen denklem sonuçları, konutta enerji etkinliği hedefine ulaşmada kadın eğitiminin önemini vurgulamaktadır. Eğitim düzeyinin artması, artan gelir ile birlikte kadınların daha enerji etkin elektrikli ev aletlerine yönelmeleri ve çevresel sorunlara olan farkındalıklarının artması ile sonuçlanacak, bu durum beraberinde artan enerji etkinliğini de getirecektir. TuREEFF (Turkish Residential Energy Efficiency Financing Facility) tarafından 2016 yılında yapılan anket çalışması sonuçları göstermektedir ki kadınlar, kendi gelirleri olmasa dahi ev aletlerinden hangisinin, ne zaman alınacağına karar veren aile bireyleridir. Erkekler ise genelde eşlerinin tercihlerini izleyen ve ödemede bulunan taraftır. Yine anket sonuçlarına göre, gelir ve eğitim düzeyi daha yüksek olan kadın ve erkekler, enerji tasarrufunu çevrenin korunması için bir yol olarak görürken, daha düşük gelirli kadın ve erkekler, enerji tasarrufunu ödenecek düşük fatura bedelleri ile ilişkilendirmektedir. Öte yandan, bir diğer anket çalışması olan ve ankete katılanların %79'unu ev kadınlarının oluşturduğu "Enerji Hanım" anketi değerlendirme sonuçlarına göre, katılımcıların %70'i elektrikli ev aletlerine ilişkin enerji sınıfı konusunda bilinçsizdir. Geceleri elektrikli ev aletlerini kullanmanın daha düşük elektrik faturaları ile sonuçlanacağı algısı toplumda oldukça yaygındır. Oysa bu düşük tarifelerden yalnızca elektrik tedarikçilerine başvurarak üç zamanlı tarife uygulamasına geçmeyi talep eden ve mekanik sayaçlarını akıllı sayaçlarla değiştiren tüketiciler yararlanabilmektedir. Tüketiciler, enerji sınıfı konusunda olduğu gibi bu tarife yapısı konusunda da bilinçsizdir. Tüm bu örnekler göstermektedir ki, düzenlemeler tek başına yeterli olmayıp yapılan tüm düzenlemelerin bilgilendirici eğitici kampanya, program ya da kamu spotları ile desteklenmesi gerekmektedir. Özellikle kadınlara yönelik politikalar geliştirilmesinin konutta enerji etkinliğini arttırma konusunda daha olumlu sonuçlar vereceği değerlendirilmektedir.

Etkinsizlik etkileri denkleminin önerdiği bir diğer önemli sonuç ise, elektrik kayıp kaçak oranlarının yüksek olduğu illerin, elektrik kullanımında da etkin olmayan iller olduğudur. Bu nedenle, bu illerde kayıp kaçak oranlarının düşürülmesine yönelik politikalar geliştirilmesi elektriğin etkin kullanılmasına yönelik hedefleri de destekleyecektir. İnsanlar kaçak kullanımda yakalanma riskini düşük görmeye devam ettikçe, yakalansalar dahi cezalar caydırıcı olmadıkça, yıllardır devam eden bu alışkanlığın terkedilmesi zor görünmektedir. Bu durum, Enerji Piyasası Düzenleme Kurumu tarafından tüm ülkede aynı elektrik tarifelerinin uygulanması ve kaçak kullanımların faturalara bir şekilde yansıtılması şeklinde belirlenen politika ile kaçağın az olduğu ve faturalarını düzenli ödeyen tüketicilere yük olmaya devam etmektedir. Bu politikanın, dağıtım şirketlerini kaçak kullanıma ilişkin çözüm arayışına yönelmekten de geri koyduğu yönünde eleştiriler bulunmaktadır (Aydın, 2016). Bu sebeple, politika üreticilerin daha etkin politikalar geliştirmeleri ve yasal düzenlemeler yapmaları gerekmekte olup, aynı zamanda bireyleri kaçak elektrik kullanımına iten sosyoekonomik nedenler kapsamlı bir şekilde irdelenmelidir. Bu noktada, kişilerin satın alma güçlerini dikkate alarak daha düşük belirlenen sosyal tarifeler ya da belli bir tüketime kadar düşük ya da ücretsiz elektrik sunmayı öngören blok tarife uygulamaları sorunun çözümüne yönelik bazı önerilerdir (Yurtseven, 2015). Ayrıca, kayıp kaçak ile mücadelede dağıtım şirketleri ve araştırmacıların geliştireceği Ar-Ge çalışmaları desteklenmelidir.

İllerde enerjinin etkin kullanımını desteklemek adına bir diğer öneri ise, yapılacak etkinlik analizleri sonuçlarına göre etkin olmayan illere etkinlik hedefleri koymak, etkin illere ise belli teşviklerde bulunmak olabilir. Bu durum, etkin olmayan illerde yaşayan tüketicileri elektriğin etkin kullanılmasına sevk edebilir.

Son kısımda çalışmanın geliştirilmesi yönünde bazı önerilerde bulunulmuştur. Öte yandan, il bazında stokastik sınır yöntemi ile konutta elektrik tüketimini ve etkinliğini inceleyen ilk çalışma olması yönüyle, çalışmamız bundan sonra yapılacak bölgesel gelişme ve enerji etkinliği çalışmalarına ışık tutacak niteliktedir.

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