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Master in Economic Development

On the renewable, non-renewable energy consumption and growth nexus in emerging economies: Empirical evidence from Turkey

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Abstract

Since carbon-emitting energy sources are the largest contributor to global warming and climate change, this present paper attempts to contribute to the current debate in energy-growth nexus in the literature. Focusing on the case of Turkey, it seeks to find out whether or not switching to a low-carbon path will be beneficial for this fastest-growing OECD economy by investigating the relationship between energy sources (both renewable and non-renewable) and economic growth over the period of 1990-2015. Based on the annual data, it uses an energy-incorporated Cobb-Douglas production function to perform an ARDL bounds test to check for long-term cointegration and a VECM approach to find the direction of causal relationship in the short-run and long-run. Empirical analysis revealed four findings: (1) all variables are cointegrated in the long-run; (2) there is a bidirectional causality running from growth to renewable energy consumption in the long-run, but no meaningful relationship is found in the short-run; (3) economic growth also drives non-renewable energy consumption both in the short-run and long-run; (4) despite the lack of relationship in the short-run, the long-run unidirectional causality shows that non-renewable energy consumption has a direct impact on the use of renewables. The outcome of the analysis indicates that energy is not a limiting factor to growth in Turkey; therefore, confirming the validity of conservation hypothesis. In the short-run, the main policy recommendation is to focus on energy conservation strategies either by curtailing the consumption or improving the efficiency without having any adverse impact on growth. In the long-run, energy diversification should be the ultimate goal. By integrating renewables into its energy mix, Turkey can decarbonize its economy, followed by the benefits including substantial debt-relief thanks to energy independence, increased energy security, and a drastic reduction in CO₂ emissions. Thus, the promotion of renewables will be vital for addressing the social, economic, and environmental concerns in the future.

Key words: Renewable energy consumption, total energy use, fossil fuels, economic growth, cointegration, Granger causality, emerging economy, Turkey

EKHS22

Master's Thesis, Second Year (15 credits ECTS)

June 2018

Supervisor: Magnus Jiborn

Examiner: Josef Taalbi

Word Count: 16993

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List of Abbreviations

ADF-test	Augmented-Dickey Fuller Test
AIC	Akaike's Information Criterion
ARDL	Autoregressive Distributed Lag
CO ₂	Carbon dioxide emissions
CUSUM	Cumulative sum of Recursive Residuals
CUSUMQ	Cumulative Sum of Square of Recursive Residuals
ECM	Error Correction Model
ECT	Error Correction Term
EU	European Union
GHG	Greenhouse gas emissions
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRF	Impulse Response Functions
KPSS	Kwiatkowski-Philips-Schmidt-Shin Test
LCB	Lower Critical Bound
Mtoe	Millions tons of oil equivalent
PP-test	Phillips and Perron Test
SDGs	Sustainable Development Goals
TFP	Total Factor Productivity
TUIK	Turkish Statistical Institute
UCB	Upper Critical Bound
VAR	Vector Autoregressive
VECM	Vector Error Correction Model
WDI	World Development Indicators

1 Introduction

Climate change has become the most defining issues of our time. It poses a threat to the well-being of humankind, threatens the biodiversity, puts a risk on resources, and imposes substantial costs on the global economy (Folke et al., 2011; Rockström et al., 2009). Given the large-scale destruction, an emergency has been declared in order to speed up the efforts in mitigating the effects of climate change.

While the historic Paris Agreement has increased the interest in climate action in recent years, the latest report published by the Intergovernmental Panel on Climate Change (IPCC) (2018) highlighted the need for a global scale urgent action in order to avoid severe and irreversible damage from extreme global warming. With this new report, the previous focus on capping warming at 2°C was updated to a new target of 1.5 °C in 2018.

To meet this goal, CO₂ emission that is scientifically found to be the key driver of temperature rise must be reduced by 470 gigatons (Gt) by 2050, according to the International Renewable Energy Agency (IRENA) (2018). Motivated by the desire to limit global warming to 1.5 °C, it argues that the use of renewables over fossil fuels will be helpful immensely in cutting CO₂ emissions for a secure future. Compared to conventional forms of energy, renewable energy is safer, cleaner and sustainable (Urban & Nordensvärd, 2013). It emits less CO₂, creates less pollution, and is beneficial for the society, economy and the environment.

A recent report published by the European Union (EU) (2018) also highlights the urgency of the topic. In the report, it is claimed that the most direct way of dealing with the problem of CO₂ emissions will require a drastic shift in the understanding of economic growth and development. Similarly, OECD (2016) also argues that transition to an alternative path of energy systems will be the key to respond to climate emergency by accelerating decarbonization of the global economy.

The fact that the promotion of renewable energy and low carbon development models will continue to be high on the global agenda adds more to the relevance of the topic. In that sense, there is substantial scope for this paper to contribute to the current debate on the energy-growth nexus. Also, energy as a key input for growth is a widely covered topic, while the literature on the renewables is limited. This gap urges for more research on the role of clean energy resources and their significance as a key ingredient of low-carbon growth models in the 21st century.

Both empirical and theoretical studies have pointed out that the acceleration of industrialization and the current energy systems indeed have a strong influence on the environment and anthropogenic climate change (Henriques & Borowiecki, 2017; Jefferson, 2008). Because most of the developed countries today have already shifted a service-based economy, those who face mounting international pressure are now emerging economies (Fotourehchi, 2017; Fouquet,

2016). Since there is a close link between energy consumption and economic growth, these countries are at a crossroads due to their growing demand for energy and high reliance on coal and petroleum-based industrialization.

This current situation presents a huge dilemma for developing nations. In this regard, this study will address the paradox of emerging countries on whether or not switching to renewable energy will benefit them in the future. For this research, the *Republic of Turkey* is selected as the case country due to its strategic position as one of the largest emerging markets in the world.

Aslan (2014) argues that Turkey's valuable geopolitical position presents huge opportunities for the use of renewables. Sözen and Kırık (2017) stress the growing energy demand factor and argue that Turkey has a huge potential to capitalize on its underutilized renewable energy resources. The latest SHURA (2018) report also claim that transition to low-carbon energy would bring substantial financial relief to Turkey's current account deficit by reducing its dependence on imported non-renewable energy sources, and thereby it would help to strengthen the Turkish economy in the near future.

Considering these anticipated benefits, it is essential to establish the nature and the direction of a causal link between total energy use¹, renewable energy consumption and growth in Turkey. Because without analytical basis and empirical evidence, formulation of strategies and national action plans towards low carbon development will fail to deliver expected results. Thus, the findings of this study will contribute to the limited literature on renewable energy trend in Turkey by comparing the potential of renewables with the actual results from energy-growth nexus analysis over the past 30 years.

This study finds that energy consumption is not a limiting factor to economic growth in Turkey, implying that the Turkish economy has already shifted from industry to the service sector. Within this context, increasing population with a rising per capita income boosts the household energy consumption; therefore, economic expansion drives higher energy use in the country. Because Turkey's energy mix is dominated by fossil fuels, such consumption pattern adds more to the carbon emissions. But the analysis has shown that non-renewable energy sources can be replaced by the renewable ones, though only in the long run.

During this transition process, the major challenge for Turkey is the lack of capital stock to fund the development and promotion of renewables across the country. Therefore, this study concludes that Turkey should implement conservation policies with a focus on energy saving and efficiency in the short-run, and later, the country should target energy diversification by integrating the renewables into its energy mix in the long-term horizon.

¹ From onwards, terms of energy use – energy consumption will be used interchangeably. In addition, because fossil fuels dominate the total energy in Turkey with 90%, energy use will also refer to “non-renewable energy consumption” in this study.

1.1 Research Aim and Questions

While the energy hypotheses have been extensively tested in the literature, studies focusing on Turkey are limited and far from being conclusive at this point. Thus, the objective of this study is to examine the pattern of energy consumption and economic growth in Turkey between 1990 and 2015. It will also search for the potential for substituting fossil-fuels with the renewables by establishing Granger causality between renewables, non-renewables and economic growth. In doing so, this study will employ a deductive approach. The main research questions are:

1. *Is there a relationship between renewable, non-renewable energy consumption and economic growth in Turkey between 1990 and 2015?*
2. *If so, does this relationship imply causation between these factors? And, what is the direction of causality?*

The findings of this research will help in answering “*whether transitioning to renewables would hurt the Turkish economy or not.*” Based on the empirical results, this study will contribute to the formulation of sound policy framework and effective energy planning strategies in Turkey’s transition to a low-carbon development path.

1.2 Outline of the Thesis

The remainder of the paper proceeds as follows. *Section 2* provides background information on the energy sector in Turkey. *Section 3* covers the previous research on the relationship between energy-growth nexus which mainly presents four relevant theories, methods, and hypotheses that have been extensively used in energy studies. *Section 4* presents the dataset, variables utilized in this research and their limitations. It also lays out the methodological framework and introduces the empirical method that best fits the dataset. In *Section 5*, key findings of the cointegration and Granger causality analysis between the variables are presented. It is followed by a discussion in *Section 6* based on the relevant hypothesis for the Turkish case, and then it compares the results with the previous studies. Finally, *Section 7* concludes with the summary of empirical findings, policy implications and areas of improvement for future research.

2 A Synopsis of Turkey's Energy Sector

Over the last two decades, an average growth rate of 6% of the Turkish economy has had a significant implication on the country's energy sector (Usta, 2016). In addition to economic growth, demographic trends and the rapid pace of urbanization also continue to put a strain on the Turkish energy market. Adding to these challenges, its heavy reliance on energy imports is considered to be a major burden on the economy. Based on the projections by IPCC's Fifth Assessment Report (2014), the geographical location of Turkey, which lays at the heart of the Mediterranean Basin, makes the country at high risk in terms of vulnerability to the adverse impacts of global warming and climate change.

According to IEA (2016), primary energy consumption in Turkey has risen from 20.4 to 97.31 millions tons of oil equivalent (Mtoe) as the country has undergone an intensive period of industrialization between 1970 and 2000. In parallel with the economic expansion and booming population, it is expected that energy demand will double by 2020, resulting in 6% increase in total energy consumption, which translates into the fastest growth in demand recorded among OECD members (ibid.).

In the face of demand pressure, there has been a three-fold increase in installed energy capacity in recent years (IPC, 2015). About 88% of this demand; however, is supplied by fossil fuels that are the main drivers of climate change as they produce large quantities of carbon emissions to the atmosphere. In Turkey, reliance on fossil fuels triggered a substantial rise in energy-related emissions. Now, it constitutes two-thirds of the total emissions in the country (ibid.).

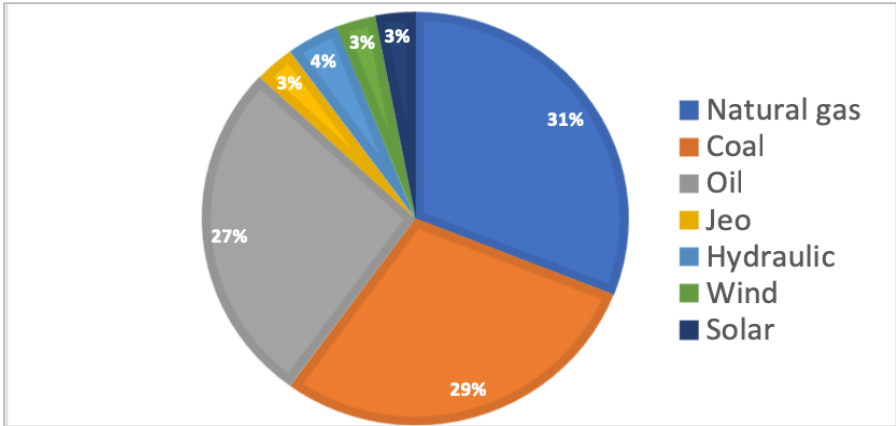


Figure 1: Energy Profile and Energy consumption Pattern (Ministry of Energy and Natural Resources of Turkey, 2015)

Figure 1 shows a snapshot of the sources of energy consumption in Turkey in 2015. As can be easily seen from the figure, its energy mix is highly carbon-intensive with a heavy reliance on fossil fuels compared to renewables which only account for 10 percent. Despite such energy portfolio, Turkey does not have adequate reserves of fossil fuels to satisfy its domestic demand

(Kilic, 2016). According to the latest OECD statistics (2019a), Turkey imports nearly 61% of its coal supply while the share of oil imports goes up to 89% of all energy demand in 2017. For natural gas, the situation is more worrisome with 99% of energy supplies is provided from imports. Overall, Turkey imports more than 75% of its energy supply to meet growing energy demand after the industrialization.

A study on the relationship between energy prices and the current account deficit in Turkey has shown that there indeed is a long-run relationship between these factors (Beşel, 2017). The study found unidirectional causality running from global oil prices to the current account deficit in Turkey between 1976 and 2016. The recent annual energy-import bill reveals that Turkey's import costs have increased by 37% in 2017 compared to 2016 not only due to the increasing energy demand but also rise in global oil prices (TUIK, 2019).

Another study found that Turkey's current account deficit in 2011 was 77.2\$ billion and the energy import bill nearly accounted for 60\$ billions of the total deficit that year (Zekayi & Nergiz, 2014). As an energy import-reliant economy, these empirical studies have shown that Turkey's rigid energy portfolio is, in fact, a major challenge to maintain uninterrupted growth and development in the future.

From that standpoint, as the energy demand grows, so does the economic burden of carbon-intensive fossil fuels in Turkey. Adding to that, CO₂ emissions per person was recorded as 6.3 tons of petroleum equivalent in 2016 in Turkey compared to 1.82 tons of petroleum equivalent in the world (OECD, 2019a). It means that Turkey's emissions per capita are well above the global average. This cast doubts on the future projections of energy and economic development for the country given that the country is also a signatory to the Paris Agreement

Within this context, Turkey formulated a "National Action Plan" in 2011. This plan laid out the climate change adaptation strategy and provided detailed information on actions and policies to address the current challenges both on the national and international level (Ministry of Environment and Urbanization, 2011). The priority areas listed as:

- I. Reforming the energy sector by diversification of resources to improve energy security,
- II. Increasing the share of renewables to serve the growing demand of population and economic expansion,
- III. Improving energy efficiency and savings to make greater use of domestic resources
- IV. Giving due importance to meeting environmental goals on local and national levels,
- V. Aligning domestic and international agendas on climate change in addition to maintaining its commitment to the global agenda for Sustainable Development Goals (SDGs).

Following these goals, the Turkish authorities drafted "National Renewable Energy Action Plan" in 2014. The plan aimed at enhancing the goals of the National Action Plan in 2011. To turn the current challenges into an opportunity, renewable energy sources are expected to play a key role in meeting the energy needs of Turkey. For that purpose, the plan sets short- mid-

and long-term targets for boosting the country’s renewable energy capacity. Under this plan, it is envisaged that 30% of gross final consumption will be supplied by renewables, and the ultimate target for electricity generation by renewables will be 50%. If these targets are achieved, it will result in a reduction of 45% of energy import bills by 2023. Besides, by shifting to low-carbon energy resources, Turkey will also reduce the energy intensity and energy-related emissions in the near future.

Table 1: Renewable energy potential for Turkey (Institute for Energy Markets and Policies (EPPEN), 2018)

Renewable Energy Sources	Potential
Hydropower	60-80 billion KWh
Wind Power	100-120 billion KWh
Geothermal Power	16 billion KWh
Solar Power	400 billion KWh
Biogas	35 billion kWh
Total	716-771 billion KWh

Table 1 displays the potential for renewables in Turkey (EPPEN, 2018). It has the second-largest solar power potential in Europe thanks to its strategic geographical location, which offers a quite temperate climate throughout the year (ibid.). Laying in between the continent of Europe and Asia and being surrounded by the sea on three sides, the country is endowed with rich wind and hydropower. For geothermal power, Turkey has the fifth largest potential in the world. Considering the potential, it offers immense opportunities for Turkey to capitalize on its renewable resources.

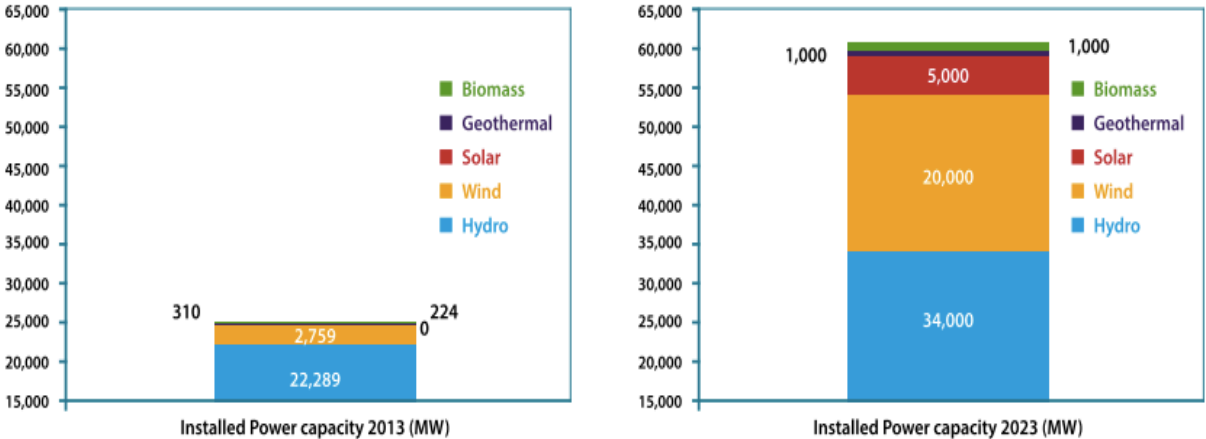


Figure 2: Installed capacity in 2013 vs future forecasts for 2023 (Ministry of Energy and Natural Resources of Turkey, 2014)

Despite its enormous potential; however, the country suffers from the underutilization of the renewables (**Figure 2**). Put differently, the major issue for Turkey is not energy availability but the ineffective use of existing resources. Considering the energy potential in **Table 1**, there is still untapped potential in Turkey’s renewable energy portfolio. According to **Figure 2**, Turkey plans to install 34GW hydropower, 20GW wind power, 5GW solar power, and 1GW geothermal and biomass capacity by 2023. Although the future scenario envisaged for renewables shows a considerable increase in actual installed energy capacity compared to past,

these targets are still low compared to Turkey's real potential in renewables, particularly in solar, wind and hydropower.

To realize its goals, Turkey has made significant reforms in the energy sector over the past decades. After embarking on a path to economic liberalization, Turkey opened its energy sector to the private sector in the late 1980s, and market-based reforms have accelerated since the 2000s (World Bank, 2015). Renewable energy has gained importance in the late 2000s as the Turkish authorities started to adopt various policies to promote the use of renewable energy across the country (Bulut & Muratoglu, 2018; Uğurlu & Gokcol, 2017).

To support transition to energy-efficient and low-carbon economy, several legislations were put into force to provide incentives for the development of capacity for renewables (Tükenmez & Demireli, 2012). However, gaps remain a major issue, especially about the tax reforms. Eco-friendly alternatives are taxed more than conventional carbon-intensive energy sources, slowing down the process of transition to clean energy in Turkey (OECD, 2019b).

Despite regulatory and institutional obstacles, several projects in capacity improvement have been in line with its National Renewable Energy Action Plan. These projects mainly dealt with lowering CO₂ emissions, increasing energy efficiency, improving the infrastructure, and building new technologies in the provision of energy (Kaya et al., 2017). Even though remarkable progress has been made in recent years, technological barriers are major limiting factor to the realization of the projects in Turkey (OECD, 2019b).

Another barrier to the deployment of renewable energy in Turkey is the lack of financial means to fund the projects (OECD, 2019b). In addition to the growing trade deficit due to energy-imports, the current economic turmoil and macroeconomic crisis add up to the already vulnerable Turkish economy (ibid.). This situation may lead to a reconsideration of priorities and eventually divert the effort and time that could have otherwise been put into renewable energy projects. To compensate, Turkey relies heavily on international cooperation and foreign-funded programs, where EU-financed projects are taking the lead in recent years.

Apart from its strengths and weaknesses, renewable energy sector has also major implications on socio-economic levels. In 2018, the expansion of renewable energy sector and industries created about 90 000 jobs in the economy. According to the latest report by IRENA (2018), the major share of the job creation is in solar energy with almost 50 000 people working in the sector. Wind power employs about 14 500 people. It is followed by hydro, geothermal and biogas providing about 18 000 employment opportunities in the country.

Taken together, these figures show how establishing a fully-functioning renewable energy sector not only bring about environmental relief, but it also makes a promising contribution to the GDP; mainly thanks to boosting employment and capital stock and to increased savings fueled by greater energy independence and improved energy efficiency in the economy.

3 Literature Review

This section sets out to provide an overview of existing literature on the relationship between energy and growth. It is divided into four sub-sections. The first one explores the role of energy resources within the historical context of economic growth. The second sub-section reviews the theories of production and growth, and how energy is incorporated into the economic models in the more recent literature. The third one focuses on the theoretical development of the energy-growth nexus and main strands of empirical research by presenting the four hypotheses debated in the literature. Finally, the last sub-section identifies the research gap and explains how the study will address it.

3.1 Role of Energy in Economic Growth Revisited

One cannot understand the link between energy and growth without understanding the importance of the role played by energy sources during the process of industrialization (Stern, 2011). Therefore, this sub-section will investigate the historical evolution of the link between energy trends and economic growth. When relevant studies in the literature are reviewed, it can be easily seen that traditional energy sources have attracted the majority of the attention whereas the literature on renewable energy has only gained momentum over the past decade due to mounting concerns about the climate change.

According to Stern & Kander (2012), energy has long been an important part of the every-day life of humankind since the pre-modern era. Looking at the data on energy consumption per capita in Europe between 1500 and 2000, they saw a significant increase in energy consumption after 1850, which occurred during the period of the first Industrial Revolution. The second peak came after the 1950s when industrialization started to kick-off all around the world. Not surprisingly, these numbers show how fundamental energy use was on the path to modern economic growth.

In a similar vein, Jonsson (2012) finds that transition to an industrial society in Britain was closely linked to energy use according to the income per capita data between the early 1850s and 1950s. Csereklyei et al., (2016) also show that energy use per capita increases over time as income grows both in developed and developing countries. Their findings confirm the long-run relationship between energy use and industrialization.

The literature on the historical linkage between energy and growth also focuses on the energy revolution from the pre-modern era to the modern era in the 21st century. From wood to coal to liquid fossil fuels and now to cleaner energy sources, there is a significant relationship between energy consumption and growth over the past century, according to Geller (2003).

On the energy revolution, Fernihough & O'Rourke (2014) underpin the importance of coal as a source of energy and an essential input in driving economic growth in the 19th century. Zou et al., (2016) focus on the general trends in the history of energy development. Despite the huge shifts in the forms and production methods of energy over the centuries, they argue that energy sources are still at the heart of economic growth.

Furthermore, Warr et. al., (2010) define energy as “the lifeblood of the economy”. Both as a form of energy source and as an economic sector, its role in fueling growth, particularly after the Industrial Revolution, cannot be ignored. Because in the absence of heat, light and power, no factories can make production to provide goods and thus jobs to people. Nor companies can provide services to its customers and jobs to people, too.

Bacon & Kojima (2016) also claim that energy is essential to improve the living standards of people. Moreover, it is considered to be the backbone of the infrastructure, industrialization, and central driver of household incomes across the globe. In the current era of the new energy revolution, low-carbon energy sources are expected to make a significant contribution to the job market as well as to the national economies by substituting the sector once dominated by fossil-fuels (MacKay, 2009).

3.2 Energy in Production: Theories and Growth Models

Although there is an extensive literature arguing that energy played a key role in the history of modern economic growth, the mainstream economics paid little attention to the role of energy as direct input in the production function. But this traditional view is challenged by ecological economists over the past decades. Therefore, this sub-section deals with the theoretical considerations on the role of energy in the economic production function.

3.2.1 Growth Models without Energy

Historically, economic growth is considered to be the ultimate goal for all countries across the world (Acemoglu, 2009; Kuznets, 1973; Kuznets & Easterlin, 1966). It refers to a rise in real per capita income (Perkins et al., 2013, p.23). Economic models are utilized to help us understanding how growth occurs (Perkins et al., 2013, p.89-91). They are a simplified form of

frameworks that helps in understanding more complex realities. The simplest workhorse model for economic growth is known as the *production function*.

The neoclassical (*Solow-Swan*) *production function* was derived from the basic *Cobb-Douglas* model to explain long-term growth. This theory assumes that economic growth is the result of two main factors of production: capital and labor, while labor-augmenting technology (A), which is exogenous in the model, is also included (Solow, 1956; Swan, 1956). Economy is considered as a closed system where output, that is the gross domestic product (GDP), is produced by the inputs of capital (K) and labor (L). As can be seen from the equation below, the expansion of primary inputs jointly determines the level of the total output as well as the rate of growth of per capita income in the long run.

$$Y_t = AF(K_t, L_t)$$

This classical model makes a distinction between primary and intermediate inputs of factors of production. While the former already exists at the start and is not entirely used up, the latter only has an indirect role since they are created under the period of consideration (Halkos & Psarianos, 2015). Moreover, intermediate inputs, such as energy and materials, are entirely used up during the production period. As a result, they do not generate economic value (ibid.). However, this assumption conflicts with the laws of thermodynamics, which imply that energy is neither created nor destroyed, but it can be reused (Ockwell, 2008).

The endogenous models following the basic Solow-Swan models such as Romer (1990) with technological change or Lucas (1988) with human capital accumulation also do not consider energy as a primary input in economic production. It shows that while the literature on economic growth is rich and diverse, energy as a factor of production is absent from the main growth models. This is because the energy neither constraints nor enables economic growth because it is only regarded as an intermediate input (Spash & Ryan, 2010).

To the contrary, Hall et al., (2001) claim that the mainstream models have a huge drawback as they assign a low value to natural resources. Nakata (2004) shows that these models are too simple to reflect the reality of the current century with increasing global energy demand, depletion of fossil fuels, environmental degradation, and climate change. Pokrovski (2003), Ghali & El-Sakka, (2004) and Lee et al., (2008) maintain that re-modelling of the production function is vital to respond the needs of developing countries since they still heavily rely on fossil energy sources to promote industrial growth.

The Solow-Swan model is unrealistic in the sense that energy still plays a major role in meeting the needs of the global economy. A growing number of studies on emissions displacement in international trade (Baumert et al., 2019; Davis & Caldeira, 2010; Jiborn et al., 2018; Kulionis, 2014) have shown that energy is not only relevant for developing countries. The global production chain continues to move to the emerging economies despite the developed countries already decoupled GDP from energy thanks to their service-based economy.

In a more recent study, it is further argued that an improved model would better inform policy-makers in formulating growth and economic development (Uribe-Toril et al., 2019). Because the newly-modified model correctly demonstrates the link between energy and GDP, it would help the countries make a better assessment while taking into account the risks associated with carbon emissions due to intensive industrialization (ibid.).

3.2.2 Incorporating Energy in Basic Growth Models

To incorporate the energy as a key input into the production function, critiques have emerged after the 1980s (Vlahinić-Dizdarević & Žiković, 2010). This alternative strand of literature, which also known as ecological economics, placed greater emphasis on the energy while capital and labor were treated as flows rather than stocks (Munda, 1997).

While mainstream economists disregard the energy's role in promoting growth, ecological economists consider it as the sole and primary factor of production (Almeida et al., 2017). Not only capital and labor but they also downplay the role of technology in driving productivity. According to their view, other factors such as capital, labor or technological advancement are only important when they drive energy consumption (Munda, 1997).

But what ecological economists ignore is the scarcity of natural resources, or within this context, non-renewable energy sources that are finite and are exhaustible in the near future (Romeiro, 2012). Even before the introduction of the growth model with natural resources, a famous report published by Club of Rome named "Limits to Growth" has raised the concern over the impossibility of sustaining the level of indefinite economic growth with finite fossil fuels (Halkos & Psarianos, 2015; Hall et al., 2001). Environmental limits to growth are outlined in the report. Among the key warnings, it is stressed that nonrenewable resource depletion and pollution would lead to the collapse of the global economy and decrease the standards of living (Meadows, 1972).

In a seminal article, Stern (2011) manages to bridge two confronting schools of thought on the subject of economic growth. According to Stern (2011), the mainstream view only valid when energy is abundant whereas ecological view better fits as energy sources become scarce in the long run. Acknowledging the outputs of the "Limits to Growth" report, Stern (2011) argues that the future will largely depend on alternative energy sources. Therefore, substantial modifications need to be done in the standard production function models in order to account for the constraints on natural resources and growth.

$$Q_t = F(A_t X_t, E_t)$$

The above formula is an alternative version of the production function suggested by Stern (2011). This equation, too, derived from the standard Cobb-Douglas economic model but it comes with specific alternations in order to integrate energy into the function. In the equation, Q represents the aggregate output, X is a general term for non-energy inputs such as capital and labor. E stands for energy inputs without making a distinction between renewables and non-

renewables. And finally, A is included to account for the technological change like Total Factor Productivity (TFP).

Based on this mechanism, the factors that could affect the relationship between energy and final output can be the substitution between energy and other non-energy inputs, technological change, shifts in the energy quality, and also shifts in the composition of the economy from capital intensive to labor-intensive economy. Thus, it can be argued that investments in low-carbon energy inputs have an enormous potential to stimulate growth in the current era of resource scarcity and climate change (Ayres et al., 2013; Foxon & Steinberger, 2011).

Recently, many studies call for the extension of growth models to include the input of renewable energy. As countries are aligning their development strategies with the carbon reduction goals agreed in the Paris Agreement, these renewable resources have a huge potential to substitute for fossil fuels (Huang et al., 2017; Uribe-Toril et al., 2019). Unlike the past, it is no longer unthinkable for developing countries to pursue renewable energy-driven paths in achieving industrialization. Moreover, renewables are now more attractive than ever given the massive cost reduction over the past decade (Andreas et al., 2017).

Because the reason why the basic economic models disregarded the energy in the production function was due to the very nature of finiteness and exhaustibility of conventional fossil fuels, the inclusion of renewable resources would make a meaningful impact in classic Solow-Swan equations (Brown et al., 2011). As argued by Huang et al., (2017) and Ayres et al., (2013), the standard model becomes more realistic when both renewable and non-renewable inputs are included. Furthermore, this would indicate the pattern of substitution within energy inputs along the stages of growth from pre-industrial to industrial and to post-industrial over the long run.

3.3 Empirical findings on the Energy-growth nexus

The literature on the energy-growth nexus has started to emerge in the early 1970s. As the oil shocks hit the world economy, prices went up and access to energy resources became more limited. To assist policy-makers and strategists in making sound decisions, these studies aimed at analyzing the issue of energy availability as well as the impact of energy prices on the global economy.

Similarly, the current interest in the field is attributed to the Kyoto Protocol and the Paris Agreement. These studies mainly investigate the impact of the transition to low-carbon pathways by putting renewable energy sources in the center of attention. How the ambitious target for GHG emissions reduction would affect the economy, what kind of energy policy a country needs and the interaction within factors of production are the most important issues that are discussed in the field in recent years.

There are two strands of literature on the causal relationship between energy use and growth. The first one is based on multi-country studies while the other focuses on single-country studies.

Within the literature, four testable hypotheses have emerged along with the four generations of empirical approaches to investigate how energy/growth affect one another. Both short-term and long-term impact can be inferred from the causality relationship results.

3.3.1 Hypotheses on the energy-growth nexus

Ever since the very first contribution by the pioneer study of Kraft and Kraft (1978), there is a growing number of studies focusing on the direction of causal linkage between energy use and growth. The reason why the topic has become widely discussed in the literature is that because important policy implications can be inferred depending on the nature of causal relationship between these variables (Apergis & Payne, 2009; Payne, 2010).

While the topic has been well-studied over the past decades, the results are rather mixed. Some studies find causality running from energy to growth or vice versa while others find bi-directional or no causality at all between energy consumption and economic growth. Based on these findings, the literature on energy-growth nexus is structured around four hypotheses: *growth, conservation, feedback, and neutrality*.²

Firstly, *growth hypothesis* implies that unidirectional causality runs from energy consumption to economic growth. This means that energy plays a key role in fueling growth. It affects the output both directly and indirectly as a complement to other factors of production, which are capital and labor. The growth hypothesis implies that an increase in energy use will eventually lead to an increase in real aggregate output, measured by GDP. It is suggested that any shocks energy supply and to energy consumption may harm economic growth. Therefore, energy conservation³ measures would not be an appropriate policy if this kind of relationship exists (Apergis & Tang, 2013; Omri, 2014).

growth hypothesis: Energy Consumption* ➡ **GDP*

Alternatively, if there is a negative relationship, it could imply a sectoral shift within the economy from energy-hungry industrial sectors to less energy-intensive service sectors. Or, this negative impact would also be associated with the energy supply inefficiencies, unproductive sectors that consume a high volume of energy as well as capacity constraints in a country. Accordingly, energy conservation measures would better fit for the given context (Bildirici & Kayıkcı, 2015; Destek & Aslan, 2017). It is also important to take into account what sector an economy is based on since lowering the energy consumption would yield different results from high-energy intensive sectors to less energy-consuming and ones (ibid.).

² For the review of the hypotheses, this sub-section mainly utilized the seminal articles by Payne (2009, 2010) and Apergis & Payne (2009, 2011).

³ The term refers to innovations and efficiency improvements within the system and/or simply reductions in consumption both in public and private energy use in order to achieve energy-savings in a country.

In contrast to growth hypothesis, *conservation hypothesis* asserts that unidirectional causality runs from economic growth to energy consumption, meaning that any change in GDP also leads to a change in energy consumption. It shows that the country is not necessarily relying on energy for driving its economy. Therefore, a positive relationship indicates that energy conservation policies, such as carbon emissions reduction, demand management, energy efficiency improvement measures, would not hinder the dynamics of growth when operating in a less energy-dependent economy (Ozturk & Acaravci, 2010a; Shahbaz, Khan & Tahir, 2013).

conservation hypothesis: GDP → Energy Consumption

In addition, if an increase in GDP causes a decline in energy consumption, this would signal constraints on the economy of a given country (Acaravci, 2010; Ozturk & Acaravci, 2010b). These constraints may result from political reasons, poor infrastructure, or mismanagement of resources that would lead inefficiencies in the energy system. Moreover, it may also be due to reduced demand for goods and services with high energy consumption. Thus, any policies concerning such relationship must address the root causes of inefficiency and political issues rather than simply implementing energy conservation measures in a country (ibid.)

The third is the *feedback hypothesis* that implies a bidirectional relationship between economic growth and energy consumption. If such is the case, two-way causality shows that these variables complement each other. Given this interdependence, more (less) energy use leads to an increase (decrease) in domestic output. Similarly, any increase (decrease) in GDP also increases (decreases) energy consumption.

feedback hypothesis: GDP ↔ Energy Consumption

In terms of policy advice, it is argued that environmental protection measures would affect energy consumption and GDP in a negative way (Aslan, 2014; Ben Amar & Kamoun Zribi, 2016). Similarly, energy conservation policies would also deteriorate growth in this setting. To the contrary, economic stimulus packages would give a boost to GDP and energy consumption across the country (Fuinhas & Marques, 2012; Soytaş & Sari, 2007).

Lastly, the fourth one is the *neutrality hypothesis* which indicates a lack of causal relationship between energy and growth. If no correlation exists, it means that any increase or decrease in energy consumption would not affect economic growth and vice versa. It mostly occurs in post-industrialized countries where a low-energy consuming service sector dominates the economy, as shown by Destek & Aslan (2017) and Menegaki (2011).

neutrality hypothesis: GDP ⊥ Energy Consumption

If the neutrality hypothesis is found, it implies that the economy is decarbonized by decoupling GDP from energy consumption, which is especially relevant for developed countries (Bozkurt & Destek, 2015; Destek & Aslan, 2017; Fotourehchi, 2017). Under such circumstances, energy conservation measures and environmental policies would not necessarily make any significant impact on domestic output. Likewise, expansive policies in energy use would not have any positive or negative effect on growth.

3.3.2 Empirical Studies

While there is a widespread agreement on these four hypotheses, empirical results on the energy-growth nexus are rather mixed in the literature. To provide a better picture, some of the selected studies are summarized in **Table 2**. They are classified by author, country, time-period, variables, empirical method, and causality relationships.

Table 2: Summary of literature on energy-growth nexus

Author	Country	Period	Variables	Other variables	Method	Causal Relationship	Hypothesis
Kraft & Kraft (1978)	USA	1947-1974	GNP, total energy consumption		Sims-Causality	Growth → Energy	Conservation
Erol & Yu (1987)	USA	1973-1984	Energy consumption, employment		Engle-Granger Causality	Growth ≠ Energy	Neutrality
Cheng & Lai (1997)	Taiwan	1955-1993	Energy consumption, real GDP	labor force	Cointegration & Hsiao's Granger Causality	Growth → Energy	Conservation
Glasure & Lee (1998)	South Korea	1961-1990	Energy consumption, real GDP		Cointegration & Granger Causality	Growth ↔ Energy	Feedback
Asafu-Adjaye (2000)	India	1973-1995	Commercial energy use per capita, real GNP	consumer prices	Johansen cointegration	Energy → Growth	Growth
Hondroyanis et al. (2002)	Greece	1960-1996	Total, residential and industrial energy consumption, real GDP	consumer prices	Johansen cointegration	Growth ↔ Energy	Feedback
Ghali & El-Sakka (2004)	India	1950-1996	Electricity consumption, GDP, agricultural GDP		Cointegration & Granger Causality	Growth ↔ Energy	Feedback
Shiu & Lam (2004)	China	1971-2000	Electricity consumption, real GDP		Johansen cointegration	Energy → Growth	Growth
Lee and Chang (2005)	Taiwan	1954-2003	Energy usage, real GDP	real gross capital formation	Pedroni panel cointegration	Energy → Growth	Growth
Soytas & Sari (2006)	China	1971-2002	Energy usage, real GDP	real gross capital formation, labor force	Toda-Yomomato Causality (TY)	Growth ≠ Energy	Neutrality
Zamani (2007)	Iran	1967-2003	Total, industrial energy, agricultural energy consumption, real GDP	industrial & agricultural value-added	Engle-Granger Causality	Growth → Energy	Conservation
Chen et al. (2008)	South Korea	1971-2001	Electricity consumption, real GDP		Johansen cointegration & VECM	Growth → Energy	Conservation
Tsani (2010)	Greece	1960-2006	Energy consumption, real GDP		Toda-Yomomato Causality (TY)	Energy → Growth	Growth
Ahamad & Islam (2011)	Bangladesh	1971-2008	Energy consumption pc, real GDP pc		Johansen cointegration & VECM	Growth ↔ Energy	Feedback
Alam et al. (2012)	Bangladesh	1972-2006	Energy consumption pc, real GDP pc, CO2 pc		Johansen cointegration & VECM	Energy → Growth	Growth
Shahbaz et al. (2013)	China	1971-2011	Energy consumption, real GDP pc	capital, labor, trade openness, financial development	ARDL & VECM Granger causality	Energy → Growth	Growth
Aslan et al. (2014)	USA	1973-2012	Energy consumption, real GDP		Wavelet analysis & Granger Causality	Growth ↔ Energy	Feedback
Shahbaz et al. (2015)	Pakistan	1972-2014	Oil, coal, gas consumption, economic growth	capital, labor force, enrollment rate	ARDL & VECM Granger causality	Growth ≠ Energy	Neutrality
Ahmad & Du (2017)	Iran	1971-2011	Energy production, economic growth, CO2	domestic investment, FDI, population density, inflation	ARDL & ECM causality	Energy → Growth	Growth
Rehman & Deyuan (2018)	Pakistan	1990-2016	Energy usage, real GDP pc	electricity access, population growth	ARDL & ECM causality	Energy → Growth	Growth

Turning to multi-country studies in **Table 3**, a meta-analysis of 100 studies by Payne (2010) finds 22.95% for growth hypothesis, 27.87% for conservation hypothesis, 18.08% feedback hypothesis and 31.15% for the neutrality hypothesis based on the country-specific results. Another study by Omri (2014) shows 29% is valid for the growth hypothesis, 27% feedback, 23% conservation, and 21% neutrality hypothesis over 43 countries surveyed.

Table 3: Summary of literature on renewable energy-growth nexus

Author	Country	Period	Variables	Other variables	Method	Causal Relationship	Hypothesis
Payne (2009)	USA	1994-2003	Renewable & non-renewable EC, real GDP	real gross capital formation, labor force	ARDL cointegration & TY Granger causality	Growth ≠ Energy	Neutrality
Sadorsky (2009)	18 Emerging economies	1994-2003	Renewable EC, real GDP pc		Panel cointegration & Granger causality	Energy → Growth	Growth
Apergis & Payne (2010)	OECD	1985-2005	Renewable EC, real GDP	real gross capital formation, labor force	Granger Causality	Growth ↔ Energy	Feedback
Apergis & Payne (2011)	Central America	1980-2016	Renewable EC, real GDP	real gross capital formation, labor force	Panel cointegration & VECM Granger causality	Growth ↔ Energy	Feedback
Menegaki (2011)	EU	1997-2007	Renewable EC, Final EC, real GDP pc	labor force	Panel cointegration & VECM Granger causality	Growth ≠ Energy	Neutrality
Yıldırım et al. (2012)	USA	1960-2010	Renewable EC, real GDP	gross fixed capital formation, labor force	Toda-Yamamoto (TY) Granger causality	Energy → Growth	Growth
Tugcu et al (2012)	G7	1980-2009	Renewable EC, real GDP	gross fixed capital formation, labor force, patents	ARDL cointegration & VECM Granger causality	Growth ↔ Energy	Feedback
Pao & Fu (2013)	Brazil	1980-2010	Renewable EC, real GDP	gross fixed capital formation, labor force	ARDL cointegration & VECM Granger causality	Growth ↔ Energy	Feedback
Lin & Moubarak (2014)	China	1977-2011	Renewable EC, real GDP, CO2 emissions	labor force	ARDL cointegration & VECM Granger causality	Growth ↔ Energy	Feedback
Al-mulali et al. (2014)	18 Latin American countries	1980-2010	Renewable & non-renewable electricity consumption, real GDP	gross fixed capital formation, labor force, trade	Panel cointegration & VECM Granger causality	Growth ↔ Energy	Feedback
Öztürk & Bilgili (2015)	51 Sub-Saharan African countries	1980-2009	Biomass EC, real GDP	trade openness, population	Panel cointegration & VECM Granger causality	Energy → Growth	Growth
Bhattacharya et al. (2016)	38 top renewable energy consuming countries	1991-2012	Renewable, nonrenewable EC, real GDP	gross fixed capital formation, labor force	Panel cointegration & VECM Granger causality	Energy → Growth	Growth
Shahbaz et al. (2016)	BRICS countries	1991-2015	Biomass energy consumption, real GDP	trade openness, gross fixed capital formation	Panel cointegration & VECM Granger causality	Growth ↔ Energy	Feedback
Kahia et al. (2016)	MENA countries	1980-2012	Renewable, nonrenewable EC, real GDP	gross fixed capital formation, labor force	Panel cointegration & VECM Granger causality	Growth ↔ Energy	Feedback
Destek & Aslan (2017)	17 Emerging economies	1980-2012	Renewable EC, real GDP		ARDL cointegration & VECM Granger causality	Growth → Energy	Conservation

In a more recent study, Marinaş et al., (2018) analyze 56 countries and conclude that 23.2% supported the growth hypothesis, 19.5% conservation hypothesis, 29.2% feedback hypothesis, and 29.2% neutrality hypothesis. Such extreme diversity within the field is a bad sign for policy design since it may not yield expected impacts in a real-life setting. Further to these concerns, Hajko (2017) raises the issue of the reliability of results. Based on the review of 100 papers, he finds that the prediction accuracy of the studies ranges from 36 percent to 56 percent irrelevant of the hypothesis it supports.

According to Ozturk (2010), inconsistency in results is mostly attributed to the dataset, time-period, and methodological approach in the studies. Şentürk & Sataf (2015) also suggest that proxy variables and omitted variable bias might be the reason why there is no clear consensus in the literature. Ghoshray et al., (2018) highlight the importance of model specification in variation in results. Furthermore, Sebri (2014) finds that substantial changes occur in the final results if a multivariate framework is utilized despite the majority of the previous studies preferred to apply bivariate models to test the hypotheses.

For the choice of research method, it is also argued that the econometric approach is highly relevant in explaining the lack of consensus within the literature. According to Payne (2010), there are four generations of empirical methods. Namely, *vector autoregressive (VAR) methodology & Granger causality testing, Engle-Granger/Johansen-Juselius cointegration & error correction models (ECM), autoregressive distributed lag (ARDL) & Johansen causality tests, panel cointegration & vector error correction models (VECM)*.

Initially, studies applied the VAR methodology, which is followed by Granger-Sims causality tests to analyze the relationship between energy and growth (Kraft, Kraft & Fu, 1978). The second-generation performed two-stage Granger procedures for checking the long-term cointegration; moreover, the inclusion of the error correction models (ECM) allowed detecting short-run causal linkages between energy and growth (Erol & Yu, 1987; Glasure & Lee, 1998).

The third type of studies used multivariate estimators by applying the ARDL model and bounds testing approach to test long-run causality along with the Johansen tests to see the short-run linkage between the variables (Masih & Masih, 1996). In order to address to shortcomings of the previous methods, panel co-integration and panel-based VECM techniques are used in the more recent studies. The validity and reliability of results improved, according to Payne (2010), Şentürk & Sataf (2015) and Yaşar (2017).

Apart from methodological issues, Carmona et al., (2017) argue that different result may arise due to country-specific-heterogeneity such as energy consumption patterns, stage of economic development and even climate conditions in countries. Omri & Kahouli (2014) find evidence that the magnitude of the effect depends on the level of development, or in other words, GDP per capita in a country. In a similar vein, Menegaki (2018, p.313) shows that the impact on energy consumption or growth gets larger based on the income level for a country.

Yaşar (2017) proves that the direction of the causal relationship indeed differs amongst different country-income groups. Using the latest generation of panel cointegration tests on 119 countries

between 1970 and 2015, the feedback hypothesis is validated for high-income countries, whereas conservation hypothesis is mostly supported for middle-income countries. Finally, the neutrality hypothesis is found relevant for low-income countries. These categorized results highlight the need for the fit between the level of development and energy policy.

In addition to a significant relationship between renewables-GDP and non-renewables-GDP, perfect substitutability between renewables and fossil fuels is also desired when deciding on phasing-out fossil fuels in the long-run (Bloch et al., 2015; Wesseh & Lin, 2018). Marinaş et al., (2018) claims that the inclusion of both factors would generate more robust estimates about the prospects for substitution between dirty and clean energy sources.

After outlining several studies in the literature, **Table 4** shows a summary of selected studies for Turkey. It can be seen that studies focusing on Turkey are not as extensive as other countries. Results differ depending on the time-period, variables and methodologies used. A general observation that can be drawn from the table is that the topic of energy-growth nexus is an unresolved issue for Turkey, too.

Table 4: Summary of literature on energy-growth for Turkey

Author	Period	Variables	Other variables	Method	Causal Relationship	Hypothesis
Terzi (1998)	1950-1991	Energy consumption (electricity), real GDP	industrial electricity consumption, price index	Engle-Granger causality	Growth <-> Energy	Feedback
Soytaş & Sarı (2001)	1960-1995	Energy consumption, real GDP		Johansen cointegration & VECM Granger causality	Energy -> Growth	Growth
Altınay & Karagöl (2004)	1950-2000	Energy consumption, real GDP		Hsiao's version of Granger causality	Growth ≠ Energy	Neutrality
Altınay & Karagöl (2005)	1950-2000	Energy consumption, real GDP		Dolado Lutkepohl test & Granger causality	Energy -> Growth	Growth
Lise & van Montfort (2007)	1970-2003	Energy consumption, real GDP		Johansen cointegration & Engle-Granger causality	Growth -> Energy	Conservation
Karanfil (2008)	1970-2005	Energy consumption, real GDP		Johansen cointegration & Granger causality	Growth -> Energy	Conservation
Erdal et al. (2008)	1970-2006	Energy consumption, GNP		Johansen cointegration & Pair-wise Granger causality	Growth <-> Energy	Feedback
Halıcioğlu (2009)	1960-2005	Energy consumption, real GDP, CO2 emissions	foreign trade	ARDL cointegration & Granger causality	Growth ≠ Energy	Neutrality
Soytaş & Sarı (2009)	1960-2000	Energy consumption, real GDP, CO2 emissions	gross fixed capital formation, labor force	ARDL cointegration & TY causality	Growth ≠ Energy	Neutrality
Ozturk & Acaravci (2010)	1968-2005	Energy consumption pc, real GDP pc, CO2 pc	gross fixed capital formation, labor force	Panel cointegration & Engle-Granger causality	Growth ≠ Energy	Neutrality
Öksüzler & İpek (2011)	1987-2010	Oil prices, real GDP	inflation	VAR & Granger Causality	Energy -> Growth	Growth
Uzunöz & Akçay (2012)	1970-2010	Energy consumption, real GDP		Johansen cointegration & Granger causality	Growth -> Energy	Conservation
Uzun et al. (2013)	1980-2010	Total electricity consumption, real GDP		VECM	Growth -> Energy	Conservation
Altıntaş (2013)	1970-2008	Energy consumption, real GDP, CO2 emissions		ARDL cointegration & TY Granger causality & VECM	Energy -> Growth	Growth
Pata et al. (2016)	1960-2014	Total oil consumption, real GDP		ARDL cointegration	Energy -> Growth	Growth

Table 5: Summary of literature on renewable & non-renewable energy-growth for Turkey

Author	Period	Variables	Other variables	Method	Causal Relationship	Hypothesis
Ocal & Aslan (2010)	1990-2010	% of renewable energy in total energy, real GDP	gross fixed capital formation, labor force	ARDL cointegration & TY Granger causality	Growth -> Energy	Conservation
Bozkurt & Destek (2015)	1980-2012	Renewable energy consumption, real GDP	gross fixed capital formation, labor force	ARDL cointegration & TY Granger causality	Growth ≠ Energy	Neutrality
Bölük & Mert (2015)	1961-2010	Renewable energy production pc, real GDP pc, GHGs pc		ARDL cointegration & ECM Granger causality	Growth -> Energy	Conservation
Şeker & Çetin (2015)	1960-2010	Renewable energy consumption, real GDP, CO2 emissions	population density, trade openness	ARDL cointegration & VECM Granger causality	Growth -> Energy	Conservation
Doğan (2016)	1995-2012	Renewable & Non-renewable energy consumption, real GDP	gross fixed capital formation, labor force	ARDL cointegration & VECM Granger causality	Growth -> Energy	Conservation
Bhattacharya et al. (2016)	1991-2012	Renewable, nonrenewable energy consumption, real GDP	gross fixed capital formation, labor force	Panel cointegration & VECM Granger causality	Growth ≠ Energy	Neutrality
Alper (2017)	1990-2017	% of renewable energy in total energy, real GDP pc	gross fixed capital formation, labor force	Bayern-Hanck cointegration & TY Granger causality	Growth -> Energy	Conservation
Bulut & Muratoglu (2018)	1990-2015	Renewable energy consumption, real GDP		ARDL cointegration & VECM Granger causality	Growth ≠ Energy	Neutrality
Bilan et al. (2019)	1995-2015	Renewable energy consumption, real GDP, CO2 emissions	gross fixed capital formation, labor force	Panel cointegration & VECM Granger causality	Energy -> Growth	Growth
Dinç & Akdoğan (2019)	1980-2016	Total energy consumption, renewable energy production, GDP growth rate		Johansen cointegration & VECM & Granger causality	Growth <-> Energy	Feedback

Given that the literature on energy-growth nexus is already limited, it is not surprising that studies on the renewables in Turkey are very few (**Table 5**). While the results are conflicting in other countries, interestingly, 50% of the studies on Turkey supports the conservation hypothesis. In that sense, results are rather coherent despite the differences in time-period, variables, and econometric method. It is also important to point out that the majority of these studies use both renewables and non-renewables as the key drivers in the production function. Depending on the causal relationship, studies that find conservation hypothesis offer significant opportunities for the transition to a low-carbon path for the Turkish economy.

3.4 Research Gap

After reviewing the previous studies, this research identified several gaps in the existing literature. Although the research into the energy-growth nexus for Turkey is rich, it is still inconclusive. In addition, the area of renewable energy-growth nexus is still underdeveloped. Studies that combine renewables and non-renewables are rare, meaning that it calls for further attention. Also, the inconsistencies arising from data and methodology needs to be addressed in order to achieve more reliable estimations and thus leading to sound policies on energy and sustainable development.

Considering these points, this research investigates the causal relationship between renewable energy, non-renewable energy and growth (measured by GDP per capita) for Turkey. **Table 6** summarizes the hypotheses and possible outcomes. Based on the results, this study will be able to answer *whether or not switching to renewable energy resources would hurt the Turkish economy in the coming years.*

Table 6: Hypotheses to be investigated

NONREN → GROWTH	REN → GROWTH	REN → NONREN
NONREN ← GROWTH	REN ← GROWTH	REN ← NONREN
NONREN ↔ GROWTH	REN ↔ GROWTH	REN ↔ NONREN
NONREN ⇎ GROWTH	REN ⇎ GROWTH	REN ⇎ NONREN

In addition, this research offers several advantages over previous studies. Firstly, by adding gross capital formation and labor force in the model, it aims to avoid omitted variables bias. It also utilizes the most recent data available, which is 1990-2015. Regarding the methodological concerns, the ARDL bounds testing method is employed to explore the long-run relationship. This is followed by the VECM Granger causality tests to analyze the direction of the causal relationship between the variables. It is argued that such techniques would improve robustness since it is designed to work for homogenous economies. Adding to these advantages, this advanced technique allows capturing causal relationship both on the short-run and long-run.

Therefore, this study contributes to the existing literature by utilizing the most advanced econometric technique combined with the most recent data available. Moreover, because the majority of investments in renewable energy is now taking place in emerging economies with a 36% increase from 2014 (REN21, 2018), it calls for further investigation whether the investments on renewables would contribute to the growth in these emerging markets. For this reason, our results would add to the existing knowledge in the emerging-country studies and may help them in formulating energy and sustainable development strategies by the taking climate change crisis into account.

4 Data

Following the empirical literature, this study utilizes annual times series data from 1990 to 2015 to investigate the causal relationship between renewables, non-renewables and economic growth in an emerging market economy: Turkey. The main reason for selecting this period is the availability of the data, which compiled from different sources.

In addition, the choice of variables is in line with the theoretical and empirical literature: renewable energy consumption, total energy use, and real GDP. Variables are used in per capita levels so that valid inference can be drawn. To account for the omitted variables bias, gross fixed capital formation and total labor force are also added to the dataset. All variables are expressed in their natural logarithmic forms to minimize the problem of skewness.

The following sub-section will provide detailed information on the data sources, construction of variables, summary statistics, and preliminary data diagnostics. Finally, it will elaborate on the limitations of data in the study.

4.1 Data Sources

As explained above, this research is built on secondary data that is collected from national and international databases. The variables are real GDP per capita (constant 2010 US\$), renewable energy consumption (TJ) per capita, energy use (kg of oil equivalent) per capita, gross fixed capital formation (constant 2010 US\$) and total labor force (in millions).

To begin with, *real GDP per capita (GDP)* is chosen as a proxy for economic growth since it is the most widely used indicator in the literature. In order to adjust for inflation, constant price level are preferred. The data was obtained from the online World Development Indicators (WDI) database from the World Bank.

Renewable energy consumption per capita (REC) is measured in Tera Joules (TJ) and is utilized as an indicator for all forms of renewables: hydro, wind, solar, geothermal, biomass, biofuels, biogas and waste. This one is also collected from the World Development Indicators (WDI) database.

Energy use (EC) represents total energy consumption and is measured in million tons of oil equivalent (Mtoe). Originally, it is obtained from the World Development Indicators (WDI) database, and then cross-checked with the official numbers on the Ministry of Energy and Natural Sources of Republic of Turkey.

Gross fixed capital formation (CAPITAL) is a measure of domestic net investment in a country and is utilized as a proxy for capital stock in the production function. It is also expressed in constant 2010 US\$ prices so that it could allow establishing a valid relationship with the inflation-adjusted GDP per capita. Data on this variable is obtained from the official database of the Turkish Statistical Institute (TUIK). It is cross-checked with the numbers on OECD statistics and the WDI database.

Lastly, *total labor force (LABOR)* is expressed in millions and represents the general level of employment in a country. It comprises of the working-age population aged between 15 and 64. The data on the labor force is initially extracted from the WDI database, and then it is cross-checked with the TUIK and OECD statistics.

4.2 Preliminary Data Analysis

Before proceeding with the actual analysis, it is an essential step to perform some pre-estimation checks to get a better grasp of data. This step provides information on the measures of central tendency, degree of dispersion, and distribution of discrete variables statistics of the data. **Table 7** presents the descriptive statistics of the raw variables in the study:

Table 7: Descriptive statistics

	Observation	Mean	St. Deviation	Minimum	Maximum
GDP	25	9362,044548	2135,514009	6709,09836	13898,74696
REC	25	0,017781684	0,001914374	0,013596424	0,021441982
EC	25	1261,677659	216,7030522	947,7563045	1656,803375
CAPITAL	25	1,49533E+11	77957368865	65399117040	3,19238E+11
LABOR	25	23027487,8	2803519,068	19234752	29710011
<i>in natural logarithms:</i>					
	Observation	Mean	St. Deviation	Minimum	Maximum
<i>lnGDP</i>	25	9,109182641	0,223051348	8,811219848	9,539553968
<i>lnREC</i>	25	-4,031538315	0,109192319	-4,297948464	-3,842404518
<i>lnEC</i>	25	7,11688296	0,173930083	6,854097406	7,412645347
<i>lnCAPITAL</i>	25	25,57738516	0,517775071	24,89162906	26,48920187
<i>lnLABOR</i>	25	16,93973252	0,117456966	16,7722292	17,20699462

A sample of 25 observation is identified for each variable. While the measures of central tendency are self-explanatory, the dispersion of GDP per capita, energy consumption per capita, gross fixed capital formation, and total labor forces is quite large, meaning that some observations are spread out from the mean. As can be seen from **Table 7**, taking the natural logarithms of the variables help addressing the skewness.

In addition to summary statistics, correlation analysis is performed to assess the direction and the magnitude of the relationship between variables. It is a useful technique to check for the preliminary relationship because the value of one variable could allow us to predict the other.

Table 8: Correlation matrix

	GDP	REC	EC	CAPITAL	LABOR
GDP	1				
REC	-0,801676706	1			
EC	0,978476031	-0,814023283	1		
CAPITAL	0,99484247	-0,776477062	0,96267678	1	
LABOR	0,952603827	-0,800590224	0,93019718	0,93430219	1

The result of the correlation matrix is displayed in **Table 8**. Looking at the coefficients, there is a large and positive correlation between the variables. Thus, it is expected that as energy consumption increases so does GDP. Similarly, as the capital stock and the labor in the country expands, GDP also increases along with the similar trend. On the other hand, renewable energy is negatively correlated with GDP. Therefore, the consumption of renewables negatively affects the GDP. Moreover, energy use and renewable energy consumption are negatively correlated. As indicated in the previous studies, such relationship is highly expected given the fact that one may substitute another in the long-run.

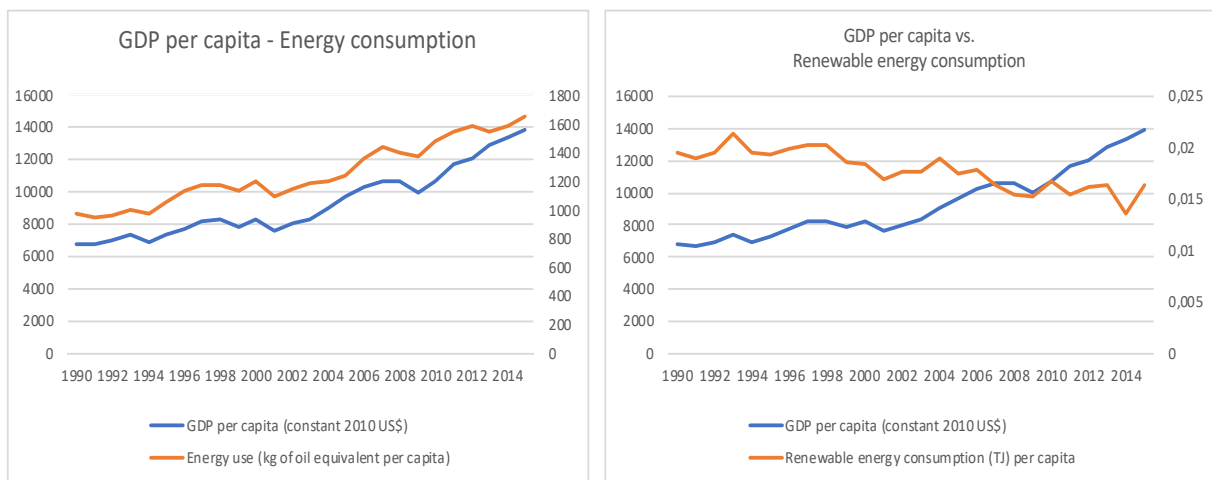


Figure 3: Energy consumption & growth trend

Based on the raw data, a graphical representation of energy-growth trends is illustrated above. **Figure 3** shows how energy consumption and economic growth patterns have changed over the years. Between 1990 and 2015, Turkey's energy use increases along with the growth in income. This is consistent with the findings of the previous studies that argue for increasing energy demand to promote economic growth (Kander et al., 2013; Stern, 2011).

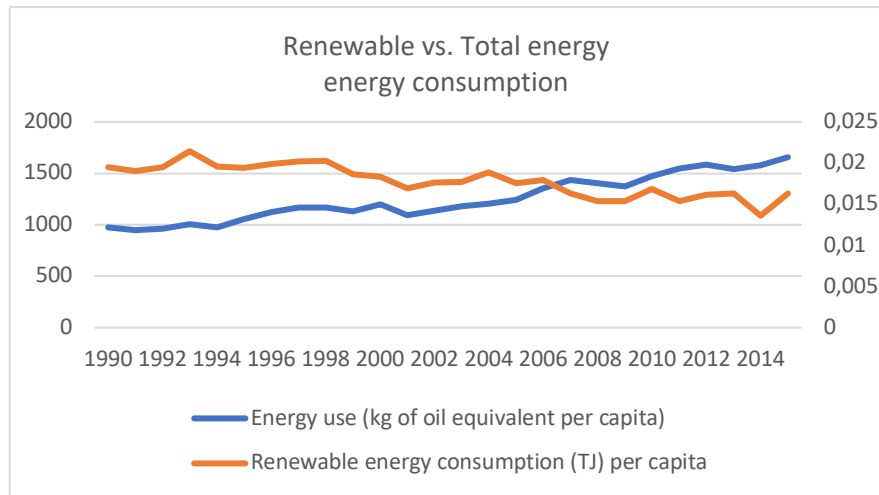


Figure 4: Renewables and Total energy consumption trend

Unlike the upward trend in energy use, **Figure 4** exhibits a decreasing trend in renewable energy consumption per capita while the total energy consumption continues to grow. Although the trend in renewables started to rise in 2014, it still contradicts with Turkey’s overambitious goal to expand installed capacity in renewables. Therefore, it makes the country’s recent efforts to switch to low-carbon energy sources highly questionable.

4.3 Limitations of Data

There are some concerns regarding the data. Firstly, the sample size is the main concern. It is argued that the small sample size may reduce the statistical power of the analysis. With low statistical power, it would be more difficult to establish a significant relationship. This would reduce the reliability of results in return.

However, the reason this study was constrained by the small sample size is due to missing data on renewable energy consumption in Turkey. Originally, this research was intended to cover the time period of 1980-2015, but the lack of data made it impossible to do so. Despite checking several sources, the inability to access proper data may be explained by either extremely low or no consumption of renewables during the 1980s.

In addition, although it is recommended to use quarterly data instead of annual data, data on renewables was not available. According to the previous studies, the former would perform better in detecting short-run relationships and thus would provide more robust estimates. With the annual data; however, short-run effects may be missed.

5 Methods

After introducing the dataset, this section sets out to present the empirical methodology. The majority of the studies on energy-growth nexus is quantitative; therefore, the same approach is taken in this research, too. Because quantitative studies are associated with the testing of relationships or theories (Creswell, 2014), it fits perfectly well with the overall research design. Since this study aims to investigate the causal relationship between energy use, renewable energy consumption and economic growth, a deductive method will allow testing the aforementioned hypotheses: growth, conservation, feedback, and neutrality.

Because the primary problem in the literature is the conflicting results not only for Turkey but also other countries (**Table 2,3,4,5**), it is argued that disagreement largely stems from the mismatch between the data and econometric methodology applied in the previous studies. That said, most of the studies still apply structural VAR techniques despite the advancement in the econometrics (Cherni & Jouini, 2017; Tugcu & Topcu, 2018; Wang et al., 2016).

This study will utilize the ARDL cointegration technique (Pesaran & Shin, 1999; Pesaran et al., 2001) to assess the relationship between the variables, followed by the VECM method to find the direction of causality among them. By combining two powerful techniques, this research aims to achieve more reliable results with the latest data. In the following sub-sections, the choice of the model and estimation steps will be described in a more detailed manner.

5.1 Model Specification

A large number of studies on energy-growth nexus utilized the neoclassical production function, which originally is derived from the Cobb-Douglas model. Pokrovski (2003) claimed that energy is a value-creating factor rather than an intermediate input. The idea of “productive energy” was further suggested by Ghali & El-Sakka (2004) in an empirical study. They found strong correlations between output growth and energy use in industrialized countries. Subsequently, Lee et al., (2008) proposed a three-factor production function where energy treated as an additional input along with the traditional inputs. And more recently, Stern (2011) also presented similar arguments and offered a newly modified version of the neo-classical growth model.

In the light of existing literature, this study employs an extension of conventional Cobb-Douglas production function as follows:

$$Y_t = F(E_t, K_t, L_t) \quad (5.1)$$

While including energy as a factor to classical growth models has become a common technique, some of the more recent studies also highlighted the need for specifying the different sources and forms of energy in the production function. Following the work of Pao & Fu (2013), Bhattacharya et al. (2016), Doğan (2016), and Destek & Aslan (2017), the modified Cobb-Douglas model is rewritten below:

$$Y_t = F(REC_t, EC_t, K_t, L_t) \quad (5.2)$$

where Y denotes real GDP per capita in billions of constant 2010 US\$; REC is renewable energy consumption per capita measured in TJ, EC represents the energy use in kg of oil per capita; K stands for the capital stock in billions of constant 2010 US\$, L is the labor force in millions, and t refers to the time period. This basic function can be converted into an econometric model in the following equation:

$$Y_t = \beta_0 + \beta_1 REC_t + \beta_2 EC_t + \beta_3 K_t + \beta_4 L_t + \varepsilon_t \quad (5.3)$$

To obtain more reliable and efficient results, it is recommended to use log-linear specification (Bhattacharya et al., 2016; Dogan, 2016). By taking the natural logarithm, the linearized function will help in reducing the risks of dynamic properties of data and corrects for heteroscedasticity of residuals. Also, it will allow interpreting the coefficients β_i ($i= 1,2,3,4$) as elasticities. The log form of the extended Cobb-Douglas model is specified as follows:

$$\ln Y_t = \beta_0 + \beta_1 \ln REC_t + \beta_2 \ln EC_t + \beta_3 \ln K_t + \beta_4 \ln L_t + \varepsilon_t \quad (5.4)$$

where $\ln Y$, $\ln REC$, $\ln EC$, $\ln K$, $\ln L$ represent the logarithms of real GDP per capita, renewable energy consumption, energy consumption, capital, and labor, respectively. β_0 is the constant term and β_i ($i= 1,2,3,4$) are the long-run elasticity estimates of the independent variables. ε_t is the error term. Based on the literature, the expected signs for $\beta_2 \beta_3 \beta_4$ are positive, while the result for β_1 's sign is ambiguous and usually depends on the level of development and the interaction between other factors of production, as discussed earlier in the literature section.

5.2 Empirical Methodology

In line with recent studies on energy-growth nexus, this paper opts for ARDL bounds testing approach to test the presence of a long-run relationship between different forms of energy consumption and economic growth, while the VECM model is constructed to capture the short-run linkage among the variables.

Although having guided by the existing literature, it is also important to check the fit between the data and empirical framework. Because selecting the appropriate methodological framework is essential to attain more robust results (Shrestha & Bhatta, 2018), a standard procedure for time series analysis is performed before proceeding to the next step. The choice of the empirical method is justified by this process and is illustrated in **Figure 5**.

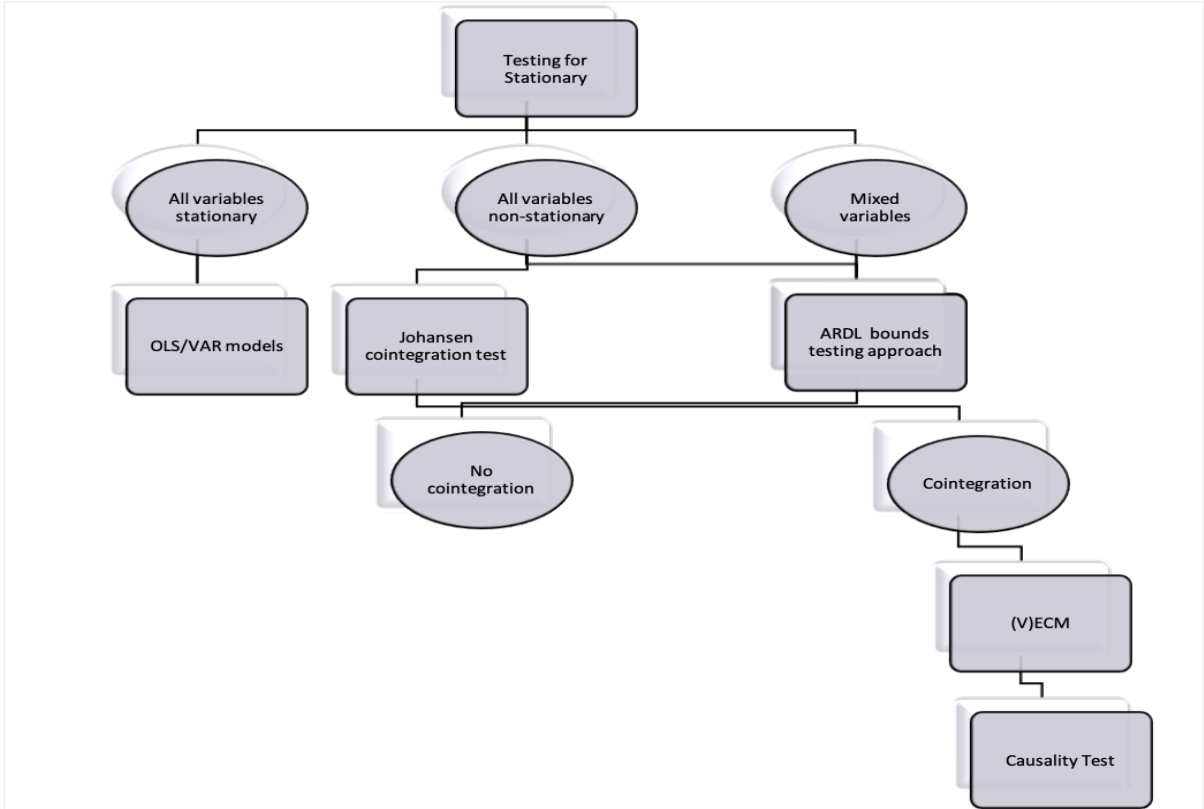


Figure 5: Method selection in time-series analysis (Author's own illustration based on Shrestha & Bhutta (2018))

As illustrated above, ARDL has an advantage over other econometric frameworks since it can be utilized regardless of whether the variables are stationary $I(0)$ at level or non-stationary but becomes stationary after taking their first difference $I(1)$. Since using the basic OLS/VAR models may bias results or indicate a non-existing relationship between the variables of interest in a study, the ARDL approach is the most efficient technique to avoid spurious results (Pesaran & Shin, 1999; Pesaran et al., 2001). In this way, it allows detecting both short-run and long-run relationship in a joint manner (ibid.).

Another merit of the ARDL technique is that it effectively removes the possible endogeneity problems and provides unbiased results of the relationship between the variables, as evidenced by the studies of Odhiambo (2008), Ocal & Aslan (2013) and Shahbaz et al. Moreover, in comparison to other cointegration techniques, ARDL models perform well even with small-size samples, which is a major issue that many of the estimation techniques usually suffer from. The model is also flexible to integrate different optimal lags in a single equation setup, while such approach is not possible in the traditional techniques (Acaravci, 2010).

Despite its advantages, the only restriction of the model is that variables cannot take the form of I(2) while it allows mixed set I(0) and I(1). Therefore, all variables must be further tested in order to ensure that none of them is integrated of order 2. To this end, starting with the analysis of the statistical properties of the series, the following sub-sections will lay out the estimation steps in constructing a proper ARDL cointegration model.

5.2.1 Unit Root Test

It is often assumed that time-series data is invariant (Shrestha & Bhatta, 2018). This implies that the mean, variance and covariance do not change with a trend over time. With a constant slope, it is easier to predict the behavior of variables as well as how they interact with each other in the long-run (Gujarati, 2003, 2011). Non-stationary series, on the other hand, offer a little value in forecasting the future because their results are not generalizable due to possible fluctuations around the trend (ibid.).

While non-stationary series is not a limiting factor for an ARDL model, the main aim is to ensure that all variables are not integrated of order I(2) rather than testing for stationarity. A simple visual inspection of graphs and auto-correlograms may help in detecting the problem in the series; however, it is recommended to perform unit root tests to ensure the validity of the results (Pesaran & Shin, 1999; Pesaran et al., 2001).

To investigate whether this condition is satisfied or not, three different models of unit root test, which are prominent in the literature, are performed: *Augmented-Dickey Fuller (ADF)* (1981), *Phillips and Perron (PP)* (1988), and *Kwiatkowski-Philips-Schmidt-Shin (KPSS)* (1992).

$$\text{Trend \& Constant:} \quad \Delta y_t = \alpha + \beta_t + \delta y_{t-1} + \sum_{i=1}^{\rho} \gamma_i \Delta y_{t-i} + \varepsilon_t \quad (5.5)$$

$$\text{Only constant:} \quad \Delta y_t = \alpha + \delta y_{t-1} + \sum_{i=1}^{\rho} \gamma_i \Delta y_{t-i} + \varepsilon_t \quad (5.6)$$

$$\text{No constant \& no trend:} \quad \Delta y_t = \delta y_{t-1} + \sum_{i=1}^{\rho} \gamma_i \Delta y_{t-i} + \varepsilon_t \quad (5.7)$$

In the *ADF test*, Δy_t is the first difference of y , ε_t denotes error terms and $\alpha, \beta, \delta, \gamma$ are parameters of the model where α is an intercept constant, β is coefficient on a time trend, δ represents root, and y_t is the variable of interest. To avoid serially correlated series, the optimal length is determined by minimizing the Akaike's Information Criterion (AIC) in the E-views software instead of manually dropping the statistically insignificant lags.

The test checks whether the parameter of δ equals zero, meaning that the series are non-stationary. The null hypothesis is $H_0: \delta = 0$, where the data series needs to be differenced for correcting non-stationary, against the alternative hypothesis $H_1: \delta < 0$ where series are

stationary. Starting with the restricted equation in 5.7, all models will be checked until the absolute value of t-statistic becomes larger than the critical value at 5%.

$$y_t = \alpha + \beta t + \delta y_{t-1} + \varepsilon_t \quad (5.8)$$

The second unit root test is PP-test. It non-parametrically corrects for autocorrelations and heteroscedasticity in the series without even requiring the selection of the optimal lag. All parameters and the null hypothesis are the same as the ADF-model. While it has an advantage over the ADF-test, PP is criticized due to its low power in rejecting the null hypothesis and may falsely find a unit root (Erdal, Erdal & Esengü, 2008). Thus, it fits better to large samples whereas the small-size samples may suffer from the wrong conclusion.

$$\Delta y_t = \alpha + \beta t + k \sum_{i=1}^t \xi_i + \varepsilon_t \quad (5.9)$$

Since both tests has some disadvantages, KPSS-test will be performed to validate the results. In Equation 5.9, α denotes intercept constant, β represents coefficient on a time trend, k is the coefficient for root, ξ_i is a random walk, and ε_t is the error term of the equation. Unlike the ADF and PP-test, the null hypothesis for the KPSS-test is stationary $H_0: k = 0$ and $H_1: k \neq 0$ for non-stationary.

That said, the major issue with the KPSS test that it tends to reject H_0 more often than other alternative tests mentioned (Dinç & Akdogan, 2019; Rahman & Kashem, 2017). Therefore, it is recommended to combine the results of all tests in order to confirm the results since alternative models can compensate for the weakness of one another.

5.2.2 ARDL Bounds Testing to Cointegration

The notion of cointegration is associated with the long-run relationship between two or more variables (Pesaran & Shin, 1999; Pesaran et al., 2001). If the linear combinations of these variables are cointegrated, it implies that there exists an equilibrium relationship in the long-run (Gujarati, 2003, 2011). Intuitively, it is expected that variables will not drift too far apart from each other. That said, long-run equilibrium is restored regardless of possible shocks to the system in the short-run.

Following the work of Pesaran et al. (2001), a two-step procedure will be implemented:

- I. Estimating the long-run relationship to assess cointegration,
- II. If cointegration exists, both short-run and long-run dynamics are estimated in a VECM model.

And finally, some stability tests and diagnostics tests will be applied to check the consistency of the model as well as to ensure the robustness of the results.

After performing the unit-root tests, assuring the order of integration, determining the optimal lags, the log-linear specification of ARDL model (unrestricted error correction model (ECM)) to test for the cointegration is as follows:

$$ARDL(p, q) = \Delta y_t = \beta_0 + \sum_{i=1}^p \beta_1 \Delta y_{t-i} + \sum_{j=0}^q \beta_2 \Delta x_{t-j} + \delta_1 y_{t-1} + \delta_2 x_{t-1} + \varepsilon_t \quad (5.10)$$

This model can also be re-parameterized:

$$\begin{aligned} \Delta \ln GDP_t = & \beta_0 + \sum_{i=1}^p \beta_i \Delta \ln GDP_{t-i} + \sum_{j=0}^{q_1} \beta_j \Delta \ln REC_{t-j} + \sum_{k=0}^{q_2} \beta_k \Delta \ln EC_{t-k} + \sum_{l=0}^{q_3} \beta_l \Delta \ln capital_{t-l} \\ & + \sum_{m=0}^{q_4} \beta_m \Delta \ln labor_{t-m} + \delta_1 \ln GDP_{t-1} + \delta_2 \ln REC_{t-1} + \delta_3 \ln EC_{t-1} \\ & + \delta_4 \ln capital_{t-1} + \delta_5 \ln labor_{t-1} + \varepsilon_t \end{aligned} \quad (5.11)$$

where Δ is the differenced operator, ε_t is a white noise term, p/q represents maximum lags for dependent and independent variables, respectively. The parameter δ_1 indicates the presence or absence of long-run equilibrium.

The decision is made based on two asymptotic critical values generated by Pesaran & Shin, (1999) and Pesaran et al. (2001): upper critical bound (UCB) and lower critical bound (LCB). If F-statistics values are greater than UCB, the null hypothesis of no cointegration $H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$ is rejected against the alternative hypothesis of cointegration: $H_0: \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq 0$. When F-statistics is less than LCB, H_0 cannot be rejected. The results are considered to be inconclusive, if F-statistics falls between UCB and LCB.

Once the cointegration relationship is established, the second step is to estimate an ECM model where both long-run and short-run effects can be identified. Because of the multivariate framework in this study, Vector Error Correction Model (VECM) is specified:

$$\Delta y_t = \beta_0 + \sum_{i=1}^p \beta_1 \Delta y_{t-i} + \sum_{j=0}^q \beta_2 \Delta x_{t-j} + \delta e_{t-1} + \varepsilon_t \quad (5.12)$$

The model can be also written as follows:

$$\Delta y_t = \beta_0 + \sum_{i=1}^p \beta_1 \Delta y_{t-i} + \sum_{j=0}^q \beta_2 \Delta x_{t-j} + \delta ECT_{t-1} + \varepsilon_t \quad (5.13)$$

where e_{t-1} is error correction term (ECT), δ is the speed of adjustment for ECT, and the remaining parameters are the same as the previous cointegration model. For a short-run relationship, the sign for δ is expected to be negative and statistically significant. Also, the value must lie within 0 and 1, showing that the system reverts to equilibrium after a shock. The speed coefficient indicates how quickly this change occurs. In the case of positive δ , deviation from the equilibrium cannot be neutralized.

After estimating the final model, several *diagnostics* such as normality, serial correlation, heteroskedasticity, and functional form tests and *stability tests* such as Cumulative sum of Recursive Residuals (CUSUM) and Cumulative Sum of Square of Recursive Residuals (CUSUMQ) will be conducted.

5.2.3 Granger Causality Tests

While the presence of cointegration implies that causality exists between variables (Engle & Granger, 1987), it does not indicate the direction which causality runs from. As a restricted VAR model, the VECM offers an alternative to standard causality tests by distinguishing between short-run and long-run causal relationship through the ECT (Bildirici, 2013). Also, the VECM is superior to other alternative tests because it allows estimations for series with different lags of order (Binh, 2011; Omri & Kahouli, 2014). By avoiding the shortcomings of the standard Granger tests, it provides better insight into the interaction among series.

With the VECM, the last step of testing the relationship between variables of interest is to apply Granger causality test. It generates three possible outcomes: I. X affects Y, II. Y affects X, III. X and Y affect each other.

The below equations are constructed for investigating the causal relationship between growth and renewable energy consumption. ⁴

$$\begin{aligned}\Delta \ln GDP_t &= \beta_0 + \sum_{i=1}^p \beta_i \Delta \ln GDP_{t-i} + \sum_{j=0}^{q_1} \beta_j \Delta \ln REC_{t-j} + \sum_{k=0}^{q_2} \beta_k \Delta \ln EC_{t-k} + \sum_{l=0}^{q_3} \beta_l \Delta \ln capital_{t-l} \\ &+ \sum_{m=0}^{q_4} \beta_m \Delta \ln labor_{t-m} + \delta_1 ECT_{t-1} + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta \ln REC_t &= \beta_0 + \sum_{j=1}^p \beta_j \Delta \ln REC_{t-j} + \sum_{i=0}^{q_1} \beta_i \Delta \ln GDP_{t-i} + \sum_{k=0}^{q_2} \beta_k \Delta \ln EC_{t-k} + \sum_{l=0}^{q_3} \beta_l \Delta \ln capital_{t-l} \\ &+ \sum_{m=0}^{q_4} \beta_m \Delta \ln labor_{t-m} + \delta_2 ECT_{t-1} + \varepsilon_t\end{aligned}$$

Granger causality test is carried out in two steps by looking at β and ECT parameters to infer short-run and long-run relationship. First, the short-run (weak) causality is examined by Wald-test statistics with a null hypothesis $H_0 = \beta_j = 0$ and $H_0 = \beta_i$ of no Granger-causality. Second is the long-run (strong) causality and it is tested by a null hypothesis $H_0 = \delta_1 = 0$ and $H_0 = \delta_2 = 0$. In both steps, the rejection of the null is based on the F-statistics. Alternatively,

⁴ The VECM Granger causality models are estimated for each pair of variables in the system; however, these equations are presented in Appendix A due to page restrictions.

looking at t-statistics of the coefficients gives the short-run causal relationship while t-statistics of the ECT shows the long-run causal relationship. In addition, pairwise Granger causality is also applied to validate long-run results. If both are significant, one can infer strong causality among the variables.

5.2.4 Impulse Response Function & Variance Decomposition Method

While the VECM Granger test is a powerful way to analyze causality in series, it does not provide variable estimates beyond the selected time-period (Soytas & Sari, 2007). Moreover, it only indicates the direction of causality while the sign of the relationships remains unanswered. According to Koop et al., (1996), this problem can be easily avoided by applying Impulse Response Functions (IRF) to visualize the destabilization in the system.

From the IRF, the initial response of one variable (for instance, renewable energy consumption) to a shock on another variable (real GDP per capita income) over various time horizons can be observed (Koop et al., 1996). Moreover, the persistence of this short-run effect can also be obtained by looking at the graphical visualizations of series.

Despite its benefits; however, IRF is considered to be insufficient since it only shows the effect of a single shock (Ahmad & Du, 2017; Kyophilavong et al., 2015). Because there may be a sequence of shocks in the system, generalized variance (VAR) decomposition method can be utilized to overcome the shortcomings of IRF (ibid.). This method is also introduced by Koop et al., (1996) and investigates the cumulative effects of shocks of one variable on the another over different time horizons.

Based on the work of Koop et al., (1996), individual contributions of each shock (for instance, GDP per capita) to the movements in other variables over different time horizons can be assessed by performing variance decompositions.

6 Empirical Analysis

This section presents the findings of the empirical analysis on the energy-growth nexus in Turkey between 1990 and 2015. The analysis is divided into two sub-sections.

First, “results” section deals with the *testing for stationary, deciding on optimal lag and testing for cointegration, building a VECM to check for causal relationship both in the short-run and long-run*, and finally *validate results with IRFs and VAR decomposition analysis* along with the stability and diagnostic tests. All data analysis and econometric implementations are done using E-views 10 statistical software package, similar to that of the studies in the field. In the “discussion” section, findings of the analysis as well as how they relate to the previous studies are discussed.

6.1 Results

6.1.1 Testing for Stationary

Because the main purpose of this study is to derive meaningful policy implications for the future transforming non-stationary series to stationary ones is the primary step in conducting a consistent cointegration analysis.

Before performing the unit root tests, variables are plotted in a graph to observe the nature of the series. A quick visual inspection of **Figure 10, 11, 12, 13, 14**⁵ reveals that the series do not exhibit stationary behavior. Since the mean of the series consistently follows either an increasing or decreasing trend, our variables are classified as non-stationary.

Another way to check whether the series are non-stationary or not is to perform regression analysis and then observe the value of R^2 and Durbin-Watson (DW) test statistics. Because the rule of thumb is that R^2 greater than DW statistics implies spurious regression, this step also validated the initial inspection results.

In the last step, unit root tests are implemented. Because the results are sensitive to model specification, all options are considered. Models with only constant and models with deterministic time trend and constant are tested. For the lag selection criteria, AIC was

⁵ Figures for non-stationary and stationary lnGDP, lnREC, lnEC, ln capital and ln labor are included in the Appendix B.

implemented due to its efficacy for small samples with less than 60 observations. The optimal lag length, however, was assigned by E-views instead of the manual testing procedure.

To determine the stationary state of the series, three different methods that are suggested in the literature are utilized. Results are displayed below in **Table 9**:

Table 9: Unit root test results

Variable	ADF-test statistics			PP-test statistics			KPSS-test statistics		
	Level	1st Δ	I(d)	Level	1st Δ	I(d)	Level	1st Δ	I(d)
lnGDP*	-1.999	-4.948	I(1)	-2.063	-4.948	I(1)	0.145	0.160	I(1)
lnREC**	-4.580	-	I(0)	-4.556	-	I(0)	0.085	-	I(0)
lnEC*	-2.934	-5.464	I(1)	-2.934	-5.824	I(1)	0.090	-	I(0)
lncapital*	-2.447	-5.396	I(1)	-2.482	-5.396	I(1)	0.117	-	I(0)
lnlabor*	-0.506	-4.961	I(1)	-0.174	-4.961	I(1)	0.165	0.415	I(1)

*model with Intercept

**model with Intercept & Trend

--All calculations are carried out under AIC--

The null hypothesis is that a variable of interest has a unit root, meaning that series are not stationary. The benchmark is set at 5% and the critical values for this significance level are -2.991 and -3.603, according to Pesaran et al. (2001) and Pesaran & Shin (1999). The final decision is made based on the absolute value of t-statistics of the series.

From the ADF-test statistics, it can be observed that lnGDP, lnEC, Incapital and lnlabor have a unit root at their levels even with a modified model, and their t-statistics still did not pass the critical values test. After taking the first difference, however, these series become stationary, while lnREC is already an integrated of order I(0) with intercept and deterministic time trend. PP-statistics also provide support for the findings of the ADF-test, although the values of t-statistics are slightly higher than the previous results.

The H_0 for KPSS-statistics is the opposite of ADF and PP-tests. The test discloses contradictory results that only lnGDP and lnlabor need to be transformed into their first difference. The remaining of the series are stationary as the null hypothesis of unit root is rejected at their level I(I) once the model is identified with intercept and trend. Based on these results, when variables are stationary at first difference, one additional lag will be added in the cointegration test.

6.1.2 ARDL cointegration

After removing the stochastic trend, the series are integrated of different orders. Having a combination of I(O) and I(I), ARDL is considered to be the most effective method in dealing with mixed series. Moreover, while there is no restriction on the use of non-stationary variables for ARDL, it is concluded from the unit root tests that series do not contain an order of integration of I(2). Thus, the next step is to determine the optimal lag length of ARDL equation since experimenting with different lags for different variables would lead to biased F-statistic results.

To find the optimal lag selection order, one-year VAR model is implemented with the initial assumption of no cointegration among the variables. After running the regression, Lag Selection option is performed on E-views and the system generated the results. The maximum lag length is selected based on the sample size. For annual data, previous studies used the lag order of 2 and the analysis is done following the same.

Table 10: Lag selection order

Lag	LogL	LR	FPE	AIC	SC	HQ
0	172.812	NA	5.81e-13	-13.984	-13.738	-13.919
1	253.289*	120.715*	6.03e-15*	-18.607*	-17.134*	-13.216*
2	273.342	21.723	1.253e-14	-18.195	-15.495	-13.478

*indicates lag order selected by the criterion (each test at 5% level).
 LR: sequential modified LR test statistics, FPE: final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

According to **Table 10**, the system selected an optimal lag order of 1 out of 2. Rule of the thumb is that the lower the value the better the module; thus, lag 1 is appropriate. Although the decision is based on the AIC criteria, several tests are performed to validate the results. While it is also possible to do the same steps for each of the respective variables individually, it is recommended to check the group unit to ensure a better fit for the module as a whole.

Before proceeding with cointegration analysis, the AIC model selection test is carried out to decide which modelling option is stronger in estimating the long-run relationship between the series. As can be seen from **Figure 6**, the ARDL (1,0,0,0,1) model is chosen over other models, which is in line with the findings of the previously implemented KPPS-test for unit root.

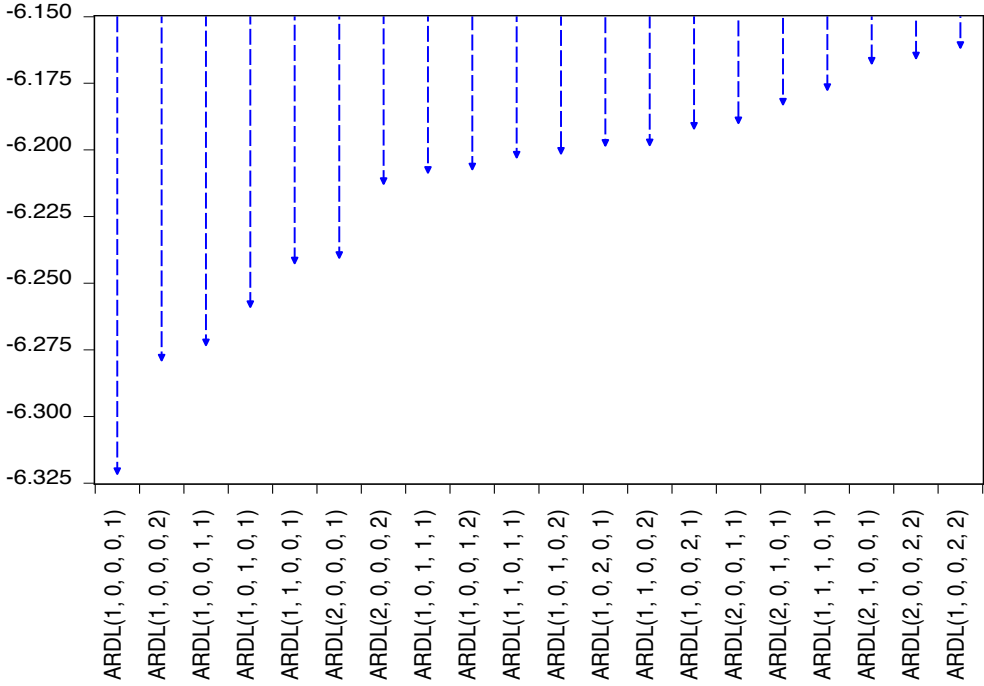


Figure 6: Top 20 models based on AIC criteria

After finding the stationary levels and obtaining the optimal lag order, the next step is to put this best-fitting ARDL (1,0,0,0,1) model in testing for cointegration. In order to establish whether there is a long-run relationship or not, the bounds test is conducted with **Equation 5.11**. The results are reported in **Table 11**:

Table 11: ARDL Cointegration analysis

Model					
lnGDP= f(lnREC, lnEC, Incapital, lnlabor)			ARDL(1,0,0,0,1)		
	F-statistic		t-statistic		
Ho: No levels relationship	11.75		-17.06		
Critical value	I(0)	I(1)	I(0)	I(1)	
	1%	3.74	5.06	-3.43	4.06
	5%	2.86	4.01	2.86	-3.99
	10%	2.45	3.52	-2.57	-3.66
	Diagnostic Tests				p-value
	Breusch-Godfrey Serial Correlation LM				0.895
	Jaque-Bera Normality				0.562
	Heteroskedsticity (ARCH)				0.309
	Ramsey RESET				0.849

Based on the optimal model, the results in **Table 11** indicate that our F-statistic value lies above the lower critical bound and exceeds the upper critical value bound at 1%, 5% and 10%, meaning that the null hypothesis of no levels relationship is rejected. Moreover, the absolute value of t-statistic also offers supportive results, providing more consistency for the presence of the cointegrating relationship among renewable energy, energy use, capital, labor, and economic growth in Turkey between 1990 and 2015.

To check the robustness of the ARDL model, several diagnostics tests are applied. According to **Table 9**, our model passes normality and serial correlation tests since their p-values are greater than 0.05. The ARCH test suggest that errors are homoscedastic. Moreover, the functional form test of Ramsey Reset shows that our model does not suffer from omitted variable bias and model misspecifications. This would improve the reliability of the long-run relationship among the series.

In addition to diagnostics tests, the stability of parameters is also checked by using the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squared residuals (CUSUMQ) tests. The former tells about if coefficients are changing systematically or not, while the latter depicts the probability of sudden changes in coefficients. Because instability of the model could increase the risk of misguiding the policy formulation process, the stability of coefficients is further assessed by the plot of CUSUM and CUSUMQ as displayed below:

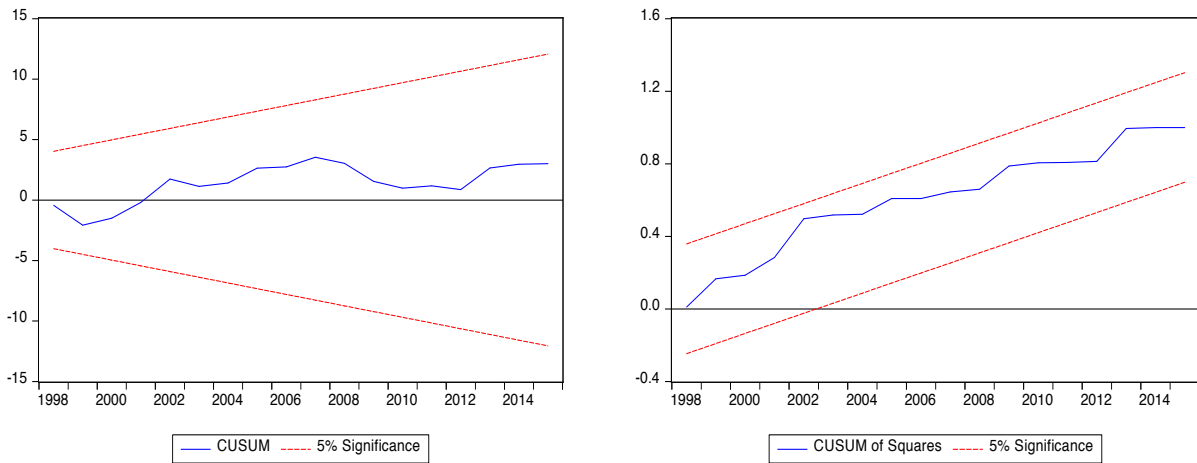


Figure 7: Plots of CUSUM & CUSUMQ

The plots are given in **Figure 7**. Because the blue line representing the CUSUM and CUSUMQ are within the red border, or in other words, 5% significance level, the null hypothesis is accepted. This is desirable since it implies that parameters are stable without being subject to structural breaks between the period under investigation. With such well-specified model, it is safe to consult the findings of ARDL function for policy recommendations on energy and economic growth in Turkey.

Once the cointegration relationship is confirmed and the robustness of the results is ensured, the next step is to run a multivariate VECM model to estimate both long-run and short-run elasticities of the coefficients. Calculations are made based on **Equation 5.13**. Again, the optimal lags are (1,0,0,0,1) derived from the AIC criterions to remove trends in the series. In the first phase of the analysis, the long-run estimation results are presented in **Table 12**.

Table 12: Long-run analysis results

Model	$\ln \text{GDP} = f(\ln \text{REC}, \ln \text{EC}, \ln \text{capital}, \ln \text{labor})$			
Long-run estimates	Coefficient	Std. Error	t-statistic	p-value
$\ln \text{GDP}$				
LNREC	-0.106	0.039	2.789	0.0982***
$\ln \text{EC}$	-0.006	0.005	0.106	0.0267**
$\ln \text{capital}$	0.316	0.015	-19.790	0.0000*
$\ln \text{labor}$	0.515	0.054	-9.400	0.0000*
cons	8.079	0.678	-9.547	0.0000*

*, **, *** symbolizes the significance at 1%, 5% and 10%, respectively.

According to **Table 12**, all variables are statistically significant in explaining the economic growth in Turkey in the long run. It can be seen that $\ln \text{REC}$ and $\ln \text{EC}$ have a negative impact on $\ln \text{GDP}$. More specifically, 1% increase in renewable energy consumption implies a downward trend in real GDP per capita by 0.10% while total energy consumption accounts for 0.006% of the decrease in the long-run.

Although statistically significant, the coefficients do not indicate a substantial negative impact on income given the magnitude is considerably small. The impact of \ln capital on \ln GDP is positive and statistically significant at 1% level. All else constant, 1% increase in gross fixed capital formation in Turkey boost economic growth by 0.316%. Likewise, \ln labor also exerts a positive impact on \ln GDP, meaning that an increase in the labor force spurs growth by 0.515% in the long run in Turkey.

In the second phase of the analysis, **Table 13** below shows the short-run estimates, which are derived from the same ARDL model. Before interpreting the coefficients, it is important to point out that $ECT(-1)$ is negative and statistically significant at 1% level, which confirms the established long-run relationship among growth, renewable energy consumption, total energy use, capital formation and labor force between 1990 and 2015 in Turkey.

In addition to the co-movement of the series, $ECT(-1)$ tells that the speed of adjustment towards the equilibrium is -0.826, meaning that the short-run deviations in the previous period are corrected by the speed of 82.6% in the future. The ECT coefficient is substantially high, but it is usually expected to be lower as converging to equilibrium takes time when several factors are at play in an economy. Therefore, any shock to the Turkish economy is neutralized by 82.6% and the system quickly goes back to its normal state within 1.16 years following the shocks.

Table 13: Short-run analysis

Short-run estimates	Coefficient	Std. Error	t-statistic	p-value
$ECT(-1)$	-0.8261	0.9758	-2.0204	0.0001*
$\Delta \ln$ GDP	0.4958	0.7616	6.6509	0.0001*
$\Delta \ln$ REC	-0.2433	0.1599	1.5214	0.9763
$\Delta \ln$ EC	-0.0197	0.3320	5.0950	0.6432
$\Delta \ln$ capital	0.2146	0.2549	8.4209	0.0001*
$\Delta \ln$ labor	0.0447	0.6964	6.9694	0.4631
cons	0.0324	0.0159	2.0347	0.0000*

*, **, *** symbolizes the significance at 1%, 5% and 10%, respectively.

Diagnostic Tests	p-value
R-squared	0.925
Adj. R-squared	0.901
Breusch-Godfrey Serial Correlation LM	0.891
Jaque-Bera Normality	0.562
Heteroskedsticity (ARCH)	0.309
Ramsey RESET	0.849

In short span of time, \ln REC negatively contributes to the \ln GDP and is not statistically significant at any level. Similarly, \ln EC is also associated with a negative effect on the real GDP per capita. In detail, a 1% increase in the use of renewables shrinks the economy by 0.24% while total energy consumption has an impact of 0.019%. On the other hand, \ln capital and \ln labor add to the real output in the short run. Changes in the capital are also associated with a 0.21% increase in the level of per capita output. However, the remaining factors except the

capital formation are found statistically insignificant in explaining economic growth between 1990 and 2015.

The lower part of **Table 13** reveal the diagnostic checks results. From the R^2 value, it is argued the model is a good fit as all the variables can explain 92% variation in the system. Breusch-Godfrey autocorrelation has a p-value higher than 0.05, meaning that the model is optimal. Moreover, the ARCH test proves the absence of heteroscedasticity and the result of Jaque-Bera test shows the normality of the residuals based on their p-values. And, finally, the Ramsey Reset test validates that the VECM does not suffer from any model misspecification as it was the case for the ARDL cointegration model. Overall, the VECM estimation results are reliable, and they offer effective recommendations on the energy-growth nexus in Turkey.

6.1.3 Granger Causality

Because the presence of cointegration implies that causal relation must exist at least in one direction, the next step is to reveal the direction of causality between the analyzed variables. This causal relationship can be easily inferred from the error correction model of ARDL. For that purpose, the Granger causality test is applied within the multivariate VECM model. Compared to standard causality tests, the VECM performs better, especially in the short-run, while the impact in the long run still needs to be assured one by one. A bivariate framework is also implemented to assure the validity of the results. Results are displayed below in **Table 14**:

Table 14: Multivariate VECM Granger Causality

Dependent variable	Short-run					Long-run
	$\Delta \ln \text{GDP}$	$\Delta \ln \text{REC}$	$\Delta \ln \text{EC}$	$\Delta \ln \text{capital}$	$\Delta \ln \text{labor}$	ECT
Multivariate						
$\Delta \ln \text{GDP}$	---	1.2725 [1.1114]	0.1582 [0.2110]	1.0351 [0.3715]	0.1972 [0.4026]*	-0.8222 [-2.0204]**
$\Delta \ln \text{REC}$	0.2433 [1.5214]	---	-0.4260 [-0.2711]	0.7569 [1.2937]	0.0626 [0.5828]	-4.1273 [-0.3853]
$\Delta \ln \text{EC}$	0.1197 [0.0595]***	-0.1862 [-0.3731]	---	0.0143 [0.0117]**	0.0111 [0.0499]***	-0.9686 [-1.0082]
$\Delta \ln \text{capital}$	0.2146 [0.8420]**	-0.6750 [-1.7612]	-0.1098 [-0.4377]	---	-0.0626 [-0.3655]***	-4.6493 [-1.3024]*
$\Delta \ln \text{labor}$	0.0447 [0.0642]***	-2.4814 [-2.3701]**	0.3829 [0.5585]***	-0.2226 [*0.0874]**	---	-0.2639 [-0.4026]*

*, **, *** symbolizes the significance at 1%, 5% and 10% for coefficients, respectively.

[] T-statistics are shown in brackets

Decision criteria is based of statistical significance of coefficients and their t-statistics.

In the short-run, there exists bidirectional causality between $\ln \text{labor}$ and $\ln \text{GDP}$ in Turkey. Such relationship implies that labor force cause growth, and in return, economic growth stimulates more employment in the country. Growth also leads to capital formation, but not the other way around. With regard to main variables of interest, the table exhibits that there is a unidirectional causality running from $\ln \text{GDP}$ to $\ln \text{EC}$. This implies that as the GDP per capita grows so does the consumption of the total energy use in Turkey. There is no significant causal relationship

observed in the short-run between lnGDP and lnREC. In addition, no relationship is found between lnREC and lnEC. For the control variables, causality runs from Incapital to lnEC but not to lnRE, while lnlabor and Incapital Granger cause each other in the short-run period.

The right-hand side of **Table 14** presents long-run causal relationship amongst the variables. It shows that Incapital and lnlabor have a two-way causal relationship with lnGDP, thus following a similar trend as in the short-run. Unlike these variables, however, there is a contradictory result for lnREC and lnEC in the long-run. Based on the t-statistics, the causal link running from one way to another eventually dies out. To find out which way causality runs from in the long-run, variables are further investigated within a bivariate framework in **Table 15**:

Table 15: Bivariate Granger Causality in the long-run

Dependent variable	Long-run				
	Bivariate	lnGDP	lnREC	lnEC	Incapital
lnGDP	---	0.9000 [0.3531]	0.0159 [0.2110]	0.3351 [0.3333]	5.8720 [0.0241]**
lnREC	14.0053 [0.0011]*	---	14.6580 [0.0009]***	13.0235 [0.0016]*	4.3812 [0.0481]**
lnEC	1.6637 [0.0210]**	2.0504 [0.1660]	---	0.9036 [0.0352]**	4.1831 [0.0530]***
Incapital	1.2446 [0.0276]**	1.8354 [0.8911]	0.1466 [0.7055]	---	4.5258 [0.0448]**
lnlabor	4.8004 [0.0393]**	0.0009 [0.09763]***	3.9885 [0.0583]***	4.8078 [0.0392]**	---

*, **, *** symbolizes the significance at 1%, 5% and 10% for coefficients, respectively.
 [] T-statistics are shown in brackets
 Decision criteria is based of statistical significance of coefficients and their t-statistics.

In the long-run, causality runs from lnGDP to lnREC and not the other way around unlike the short-run pattern. This implies that as the GDP per capita grows, it triggers more renewable energy consumption in Turkey. Likewise, lnGDP also causes more energy use in the country, while the total energy consumption does not have any effect on the real per capita income. Bivariate models also show that there is a one-way causal relationship between lnREC and lnEC, which signals substitutability between energy sources for Turkey in the long-run.

With regard to control variables, bidirectional causality running from labor to renewable energy consumption, and vice versa. Capital formation has a direct effect on the use of renewables but not the other way around. For total energy use, both capital and labor are related; however, energy use does not improve the capital stock in the country. Similar to short-run findings, GDP per capita has a one-way relationship with capital, while bidirectional causal linkage with labor is observed for Turkey. Lastly, capital stock and employment have a strong causal relationship in the long-run, as well.

6.1.4 Impulse Response Function & Variance Decomposition

In order to ensure the robustness of the results, IRF and VAR Decomposition methods are employed. The main aim of the IRF is to analyze the impact of a random shock that is not fully explained by the Granger-causality test. On the VAR decomposition, it discloses the sources of shocks both in the variable and also shows the cumulative effect of shocks within the system as a whole. By decomposing the pattern of shocks, it provides valuable insights about the degree of causality in addition to the direction of causality between the variables.

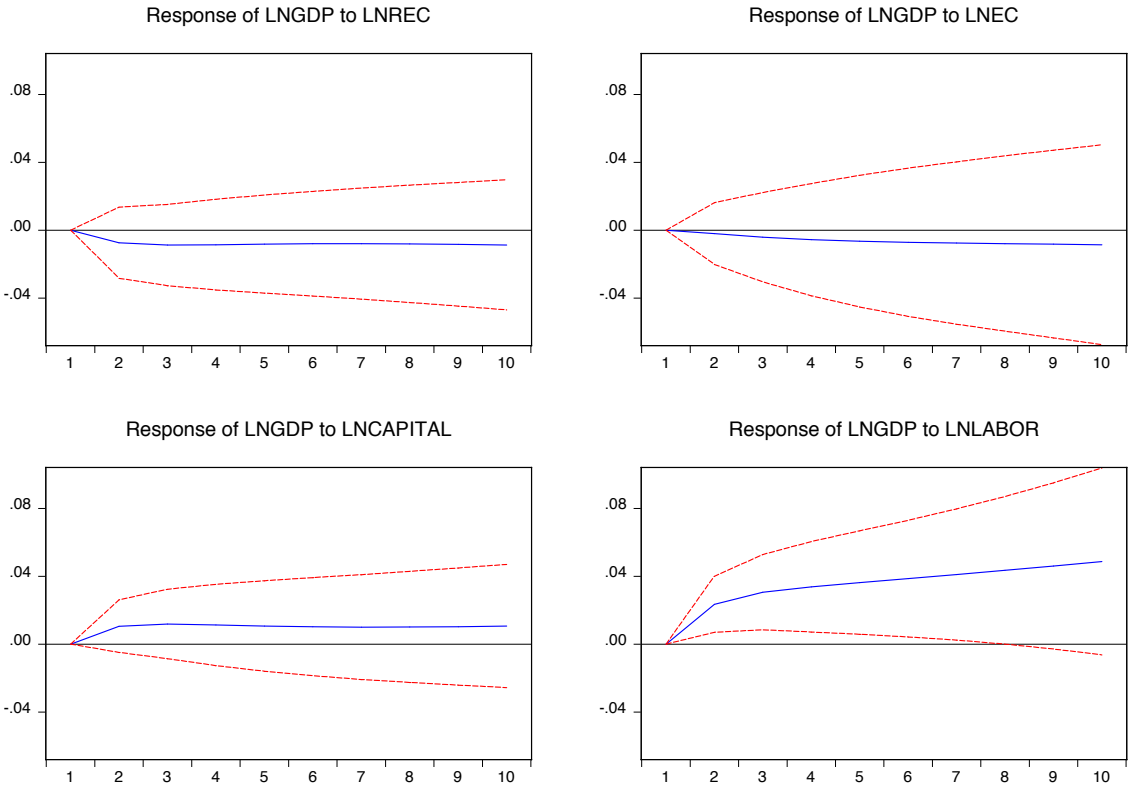


Figure 8: Response to Shocks 1

Figure 8 illustrates the shock and response pattern over the long run and helps in tracking how these variables affect one another. Assumptions are made within a period of 10 years. The response of lnGDP to one standard deviation shock in lnREC, lnEC, lnCapital, and lnLabor is displayed in **Figure 9**.⁶ Blue lines are IRF while the red lines represent 95% confidence intervals. All IRFs lie within the intervals means that there is a long-run significant relationship between these variables and thereby confirming the previous findings.

In detail, the first figure implies that the initial response of GDP per capita to a one standard deviation shock in renewable energy is negative in the earlier periods. After period 2, the response remains constant. In the second figure, the response of GDP per capita to a shock in total energy consumption is negative and follows a stable pattern over the long period. For capital shocks, there is a positive trend affecting growth, but the impact gradually decreases

⁶ IRF results for all variables can be found in Appendix C.

over longer horizons. Lastly, shocks in labor receive a substantial response from GDP per capita with a peak from period 1 to 2 and the trend is consistently positive afterwards.

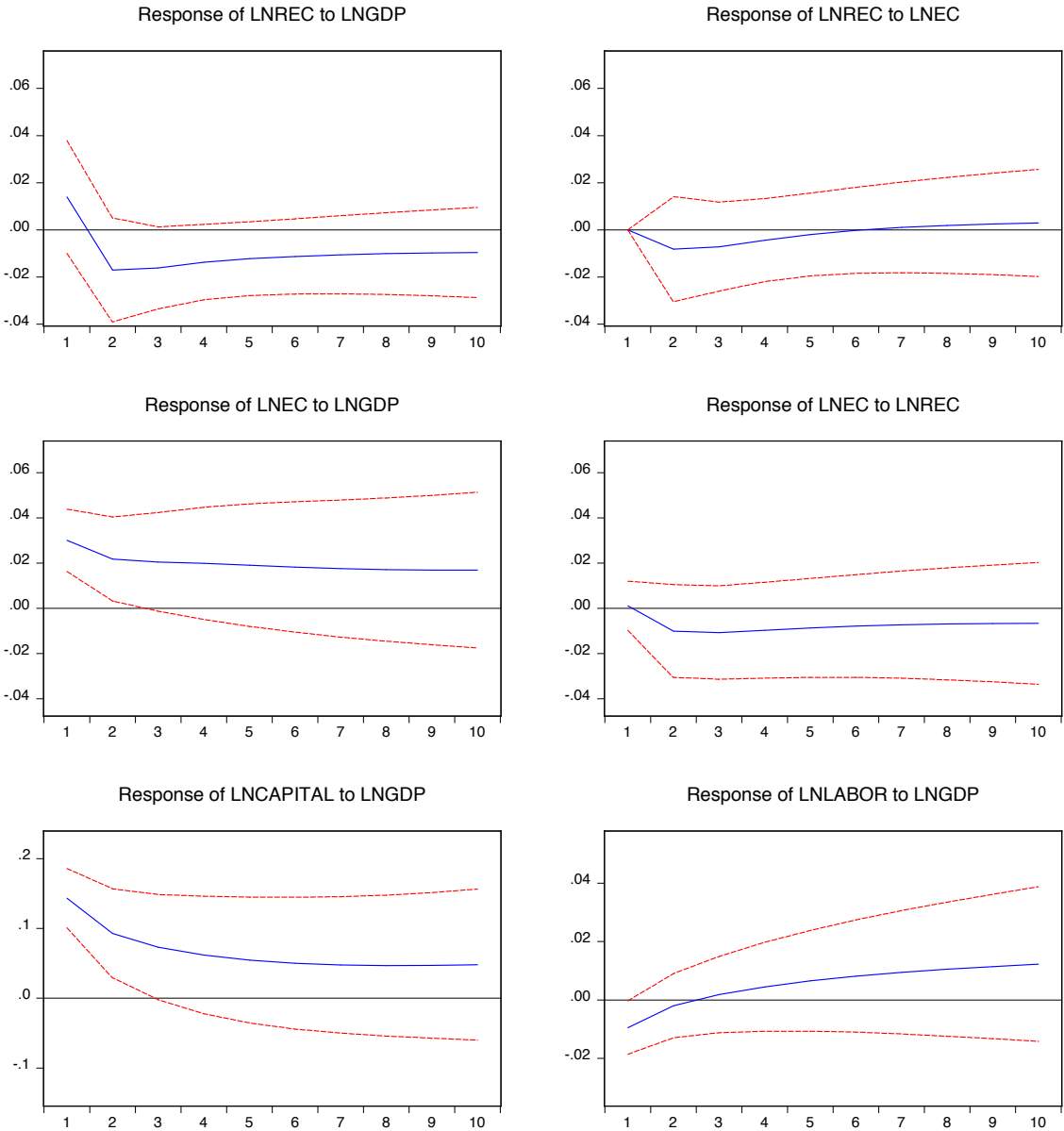


Figure 9: Response to Shocks 2

Alternatively, how variables react to a standard error shock in growth is shown in **Figure 9**. The response of renewable energy consumption to GDP per capita shocks starts with a sharp decline and continues to move negatively later in the future. On the contrary, the response of total energy consumption is always positive and its pattern does not alter with the time horizon. Capital is negatively affected after an unexpected shock in the economy. The response of labor is eventually stabilised after it moves above the zero-line. Finally, the shock-response structure between renewable energy and total energy consumption starts from zero and it further decreases in the later periods.

Overall, the findings of **Figure 8 & 9** show consistency with the ARDL and VECM results. Also, these findings improve the reliability of the speed adjustment rate. Because the adjustment is fast with 1.16 years after the shocks, figures show that the trends are corrected in the earlier stages and the system is stabilized after period 2.

In the final step, the VAR decomposition, which is the percentage of unexpected variation in variables as a byproduct of shocks, is illustrated below. The variance period is 10, so the analysis shows a forecast of 10 years into the future based on the present relationship among the variables. In addition, the economic significance of the impact can also be inferred from this error variance decomposition analysis. Results are reported below in **Table⁷ 16, 17 and 18:**

Table 16: Variance Decomposition of real GDP per capita

Variance Decomposition of LNGDP						
Period	S.E.	LNDP	LNREC	LNEC	LNCAPITAL	LNLABOR
1	0.04	100.0	0.00	0.00	0.00	0.00
2	0.05	78.32	1.61	0.11	3.38	16.68
3	0.07	62.90	2.55	0.40	4.98	29.17
4	0.08	53.15	2.90	0.73	5.49	37.73
5	0.09	46.48	3.00	1.04	5.54	44.05
6	0.10	41.27	2.98	1.29	5.43	49.02
7	0.11	37.25	2.93	1.49	5.25	53.08
8	0.13	33.99	2.86	1.64	5.06	56.45
9	0.14	31.30	2.80	1.75	4.87	59.28
10	0.15	29.06	2.74	1.83	4.70	61.68

Table 16 shows separate component shocks to real GDP per capita income in Turkey in 10 years. In the short-run, other variables in the module have minimal power in influencing growth at all. However, the contribution from labor is rising gradually from 16% to 61% while the impact of GDP per capita itself diminishes in the long-run. The table reveals that growth in the future will be largely explained by shocks in the labor force in Turkey.

Table 17: Variance Decomposition of Renewable energy consumption

Variance Decomposition of LNREC						
Period	S.E.	LNDP	LNREC	LNEC	LNCAPITAL	LNLABOR
1	0.06	5.34	94.66	0.00	0.00	0.00
2	0.06	11.40	83.41	1.58	0.68	2.93
3	0.07	16.18	77.81	2.56	0.74	2.83
4	0.07	18.81	72.81	2.77	1.27	4.33
5	0.07	20.34	68.41	2.66	1.85	6.74
6	0.07	21.27	64.42	2.49	2.31	9.52
7	0.08	21.79	60.72	2.35	2.64	12.50
8	0.08	22.01	57.23	2.26	2.88	15.61
9	0.08	22.03	53.90	2.21	3.05	18.81
10	0.09	21.91	50.69	2.18	3.17	22.05

⁷ VAR Decomposition results for control variables can be found in Appendix D.

In **Table 17**, sources of the shocks to renewable energy consumption are reported. Initially, the variable itself has a strong influence on predicting itself, while the share of other variables is negligible. It means that the variable strongly predicts itself from year 1 to year 10. From short-run to long-run, the contribution of innovative shocks of GDP per capita and labor to renewable energy consumption goes up substantially. According to these estimations, almost 94% of changes in renewable energy consumption in Turkey can be explained by these three variables in the long-run.

Table 18: Variance Decomposition of Total energy use

Variance Decomposition of LNEC						
Period	S.E.	LNDP	LNREC	LNEC	LNCAPITAL	LNLABOR
1	0.04	55.16	0.08	44.77	0.00	0.00
2	0.05	47.81	3.55	35.63	3.33	9.68
3	0.06	44.62	5.41	27.98	5.23	16.75
4	0.07	42.82	6.10	22.53	6.20	22.35
5	0.08	41.17	6.24	18.62	6.65	27.32
6	0.08	39.38	6.12	15.77	6.80	31.92
7	0.09	37.48	5.89	13.64	6.77	36.21
8	0.10	35.56	5.60	12.00	6.63	40.20
9	0.11	33.67	5.31	10.70	6.43	43.88
10	0.11	31.86	5.02	9.64	6.21	47.26

Table 18 shows that both the GDP per capita and the total energy variable itself are a strong predictor of the changes in the system. In the early years, the influence of other variables in the module is insignificant. This implies that these variables exhibit strong exogeneity, meaning that weak influence in predicting changes in total energy use in the future. However, in the later period, the explanatory power of labor rise gradually from 9% to 47%, thus showing a strong impact on total energy consumption in the future while the other variables remain insignificant.

Taken together, findings obtained from the IRFs and the VAR decomposition analysis partially support the Granger-causality results reported earlier. For the GDP per capita, the variation that stems from capital formation is barely 5% and this contradicts with the previous results. Similarly, capital does not seem to contribute much to renewable energy consumption as well as total energy use in Turkey. This entails that there might be some problems associated with capital formation because it is not leading to economic growth in the country.

6.2 Discussion

The empirical results of the ARDL and Granger causality tests are interpreted in this section. To provide a better understanding, the overall findings of the analysis and the corresponding hypotheses are presented below in **Table 19**:

Table 19: Long-run & Short-run Causality and Hypotheses

Long-run	Causality	Hypothesis
Main variables	GDP per capita -> Renewable energy consumption	Conservation
	GDP per capita -> Total energy use	Conservation
	Total energy use -> Renewable energy consumption	Unidirectional
Relationship		
Main variables vs control variables	Renewable energy consumption <- Capital formation	Conservation
	Renewable energy consumption <-> Labor	Feedback
	Total energy use <- Capital formation	Conservation
	Total energy use <-> Labor	Feedback
	GDP per capita -> Capital formation	Unidirectional
	GDP per capita <-> Labor	Bidirectional
Capital formation <-> Labor	Bidirectional	
Short-run	Causality	Hypothesis
Main variables	GDP per capita - Renewable energy consumption	Neutrality
	GDP per capita -> Total energy use	Conservation
	Total energy use - Renewable energy consumption	Neutrality
Relationship		
Main variables vs control variables	Renewable energy consumption - Capital formation	Neutrality
	Renewable energy consumption -> Labor	Growth
	Total energy use <- Capital formation	Conservation
	Total energy use <-> Labor	Feedback
	GDP per capita -> Capital formation	Unidirectional
	GDP per capita <-> Labor	Bidirectional
Capital formation <-> Labor	Bidirectional	

In the long-run, cointegration relationship between economic growth, renewables, and total energy use that dominated by non-renewable resources is established. Results show a unidirectional long-run causality running from GDP per capita to total energy use and renewable energy use. As a result, the conservation hypothesis is confirmed for Turkey over the long horizon.

On the *energy-growth nexus*, it implies that energy consumption does not necessarily drive growth but the economic growth results in more energy consumption in the country both in the short and long-term. Therefore, any shock to the real GDP per capita will have a direct effect on the total energy use. In this regard, Turkey's heavy reliance on foreign energy may have serious results unless the energy portfolio is diversified to accommodate supply shocks.

This finding is consistent with the empirical works of Lise & Van (2007), Karanfil (2008), Öztürk et al. (2010), and Uzunöz & Akçay (2012). According to Öztürk et al., (2010), there is a strong linkage between the degree of economic growth and energy consumption behavior in a country. While Turkey's service-based economy does not need an energy input to drive industrial output, higher disposable income will lead to an increase in residential energy consumption, as argued by Kander et al., (2013). This situation can be observed in the growing demand for electricity in particular for the use of electronic devices in households in Turkey.

In addition to the direction of causality, it is also important to take into account the nature of the relationship. Between 1990 and 2015, there is a negative relationship between energy use and growth in Turkey. This would signal the limitations of the energy sector in responding to the growing demand of households. In the literature, it is argued that this could be due to poor infrastructure, mismanagement of energy resources, or even institutional shortcomings that cause inefficiencies in the provision of energy (Acaravci, 2010; Ozturk & Acaravci, 2010b).

Within this context, conservation policies such as energy savings, efficiency and diversification of energy portfolio with renewables will not have any adverse impact on the growth rates in Turkey, given that the real GDP per capita does not rely on energy-led industrial production. However, as the negative relationship indicates, the initial step must be addressing the root causes of the inefficiency rather than solely formulating energy conservation strategies. If not, these solutions will not bring about intended results, and energy import bill costs continue to be as high as the past years.

On the *renewable energy-growth nexus*, conservation hypothesis is similar to that of fossil fuel energy sources. Intuitively, it is reasonable to establish a causality running from GDP per capita to renewable energy given that deployment of renewables is usually associated with high fixed costs in the beginning (Bozkurt & Destek, 2015; Destek & Aslan, 2017). The causal relationship tells that the expansion of renewable energy in Turkey depends largely on resources generated by economic growth, which can also be observed from the VAR decomposition estimates. Almost 22% of the change in renewables is influenced by the shocks originating from the real GDP per capita over the long run.

While it is already quite costly to supply almost 90% of the energy supply from imports, increasing the share of low-carbon alternatives in the economy requires substantial investment in R&D technologies and infrastructure at the very beginning, as discussed by Xie et al., (2018). Perhaps, this also explains why the nature of the relationship is negative. As an emerging country, Turkey's economy is not strong enough to support the development of renewables on its own. Thus, it is no surprise that the country seeks foreign assistance on technical issues and targets external funding for the implementation of infrastructure projects.

Because negative relationship highlights the fact that capitalizing on the abundant yet underutilized resources will be challenging, this situation also explains why the neutrality hypothesis is valid for Turkey in the short-run. A lack of short-run relationship between renewable energy consumption and real GDP per capita is indeed rational since investments made in technology and infrastructure for renewable do not pay off in the early stages. To the contrary, it will take a considerably long amount of time to generate returns from renewable energy sources.

On the *renewables-non-renewables nexus*, unidirectional causality exists for Turkey between 1990 and 2015, while in the short period no relationship is found between these variables. The long-run causality is well established both in the theoretical and empirical literature. It is related to the possibility to substitute between different forms of energy sources. In this context, this tells that clean energy sources can be an alternative to total energy consumption in Turkey where fossil-fuels have the major bulk of share.

Since increasing the use of renewables will eventually cause non-renewable sources to phase out, it is logical to have a negative relationship. And, it is also confirmed by our analysis. Moreover, the neutrality hypothesis in the short-run is also expected. It can be argued that transition to low-carbon path does not happen overnight but rather a long and painful process, as the previous instances in the world have indicated (Bozkurt & Destek, 2015; Destek & Aslan, 2017). For Turkey, it shows that the share of renewables in the short-run is so small that it does not make any impact on fossil-fuels or economic growth.

With regard to the remaining factors of production, the causal relationship running from or to capital and labor in Turkey is also examined. In the long-run, there is a one-way positive linkage between renewable energy consumption and capital stock in Turkey, though being insignificant. This unidirectional relationship confirms the previous findings of Oguz & Ocal (2013), which highlight the importance of high levels of investment for initial development and promotion of renewable energy consumption in Turkey. In the short-run, no causal relationship between these variables indicates that return to investment on renewables requires a longer time period, as also argued by Bulut & Muratoğlu (2018).

Contrary to these findings; however, the VAR decomposition analysis reveals the impact of capital stock is extremely low even over a 10-year horizon. This might be due to ineffective use of capital stock in investing renewables. Or, it could be explained by the reliance on external sources in funding R&D and infrastructure projects for expanding renewable energy use across the country (Xie et al., 2018). This is currently the case for Turkey as several projects running under the guidance of the EU and the World Bank in recent years.

The relationship between renewable energy and labor exhibits two-way causal linkage in the long-run. As discussed before in “*A Synopsis of Energy Sector in Turkey*” section, this result is not unexpected since the renewable energy sector created a significant number of employment opportunities in the country. As labor grows, it adds more value to the sector. Within this interdependent relationship, both sides feed one another. But there is only one-way causal linkage running from renewable energy consumption to labor in a shorter time-period. It means

that the contribution of labor to the development of the renewables has no significant influence. As a result, it cannot trigger a higher level of consumption in the short-run.

For the non-renewable dominated total energy mix and control variables, a similar relationship is found similar to the long-run analysis. The unidirectional causality running from capital to energy indicates how available capital stock in Turkey is crucial to pay for energy-import bills. This relationship is significant both in the short and long-run, signaling Turkey's heavy reliance on imports to satisfy growing energy demand.

Regarding the labor, a two-way causal relationship is found for both time periods. The rationale behind such relationship is widely discussed in the literature (Bacon & Kojima, 2016; Menegaki, 2014), showing the interdependence between two variables. The more the energy consumption in a country, the more it expands energy production. In return, it increases the need for more labor; thus, stimulates employment in the energy sector.

Lastly, the relationship between the real GDP per capita, capital stock and labor is discussed. Bidirectional causality is found between labor and growth in addition to a positive and significant relationship between 1990 and 2015 in Turkey. It shows that as the economy grows, it creates more jobs; and in return, these jobs contribute to the GDP in the country both in the short and long-run.

As for capital, there exists a positive and significant relationship with economic growth in Turkey. A unidirectional causality runs from growth to capital formation, but the influence of capital as an input to drive the economy is weak, as also revealed by the VAR decomposition analysis. Thus, it can be argued that some inefficiencies in the country prevent investment and national savings to stimulate economic growth. This may stem from capital market inefficiencies, lack of incentives due to the political and institutional framework, and more importantly, corruption in Turkey. These factors might explain how capital stock disappears over time, so it cannot add to the economic growth in return.

7 Conclusion

7.1 Summary

Over the past two centuries, energy has been a fundamental pillar of modern economic growth. It is now a well-established fact that today's developed countries have greatly benefited from fossil fuel-sourced energy to drive their industrial growth. However, the current climate emergency presents a new dilemma for emerging economies. In the pursuit of a cleaner and safer energy sources, renewables emerged as an alternative to replace fossil fuels that are limited in addition to having a detrimental impact on the environment.

Given the importance and relevance of the topic, this study aimed at investigating the role of renewables to determine whether they contribute to economic growth in emerging countries. Among these countries, Turkey is an interesting case with increased energy demand to respond to the needs of a growing population as well as its heavy reliance on imported oil and gas. In addition to being one of the fastest-growing emerging markets in the world, the country is endowed with abundant yet underutilized renewable energy resources.

To this end, this study examined the effect of renewable and non-renewable energy sources on the real GDP per capita growth in Turkey between 1990 and 2015. Using the Cobb-Douglas production function, it explored the presence of a long-run relationship with the ARDL cointegration technique and then established the direction of causality between these series by applying the VECM Granger Causality approach. IRF and VAR decomposition methods are also employed to further validate results.

Results from the ARDL analysis confirmed that these variables are cointegrated from 1990 to 2015. A negative relationship exists, which highlights the high initial costs associated with renewable energy use as well as the expensive energy import bills to supply rapidly growing energy demand in Turkey. This implies that neither renewables nor fossil-fuels stimulate growth but rather put strains on the Turkish economy.

Our results also showed the short-run and long-run causal relationship among these variables. According to the VECM test results, there is no significant relationship between renewables and the real GDP per capita, while growth is found to be the main driver of the fossil fuel use in the short run. The neutrality hypothesis between these two forms of energy implies that the possibility to substitute non-renewables with clean energy sources is low over a short-term horizon. This finding is well in line with the view that the current economy is so integrated with fossil-fuel systems, therefore it will take more time to actually replace them in the future.

In the long-run, causality test results confirm the conservation hypothesis for Turkey. Within this context, growth is the main driver of energy consumption (both renewable and non-renewable) in Turkey. This finding is entirely consistent with the expectations for a middle-income level service-based country like Turkey. Also, there is a unidirectional causality running from non-renewable energy sources to renewables, which means that as fossil fuels phase-out, clean energy sources can be used as an alternative in the near future.

Although switching to renewables comes with the benefit of cutting the energy import costs, the negative relationship revealed by the ARDL analysis shows that the biggest challenge for making a transition to a low-carbon path in Turkey is lack of capital stock. Therefore, to support the development of a new system for clean energy sources as well as to promote the expansion of renewable energy use across the country, the Turkish government must account for these relationships when formulating energy policies and planning the long-term development.

7.2 Policy Implications

Since energy conservation policies do not have any adverse effects in this context, the primary areas of focus for Turkey are to prioritize short-term actions: reducing carbon-emitting energy use and improving energy efficiency, especially in the household sector. Regular evaluation of the outcome and assessment of the progress will be key to turn short-term energy savings into larger gains in the long-run. Moreover, the effective use of energy sources will also help in lowering the excessive CO₂ emissions, thereby minimizing the negative environmental impact.

This step needs to be accompanied by domestic energy production with particular attention to the renewables. It is recommended that Turkey should integrate renewables with the largest potential, such as hydro, solar, wind, into its energy mix in the long-term period. In order to capitalize on its abundant resources, the private sector should be encouraged to take an active role considering the current technological and financial challenges. Offering a secure environment for both domestic and foreign investors will be an important strategy in developing energy infrastructure and fostering innovation in the country.

All in all, by combining comprehensive energy policies with right investment incentives, renewables can be a remedy for Turkey's main problems regarding energy security and energy dependency. Further to economic benefits, renewables will also bring many social and environmental benefits such as increased job creation, improved well-being thanks to less polluting green energy sources, and finally considerable reduction in CO₂ emissions. Because GDP is considered to be a too narrow measure of development, these factors together would add value to the social, economic and environmental prosperity in Turkey in the future.

7.3 Limitations of the Study and Future Research

While this research has fulfilled its objectives and has extended the current understanding of the link between renewable energy consumption, non-renewable energy use and economic growth in Turkey, it is still subject to several limitations concerning the data, selection of variables and methodological approach.

Firstly, the lack of data availability on renewable energy consumption before the 1990s constrained this study with a small sample. In that sense, there is still room for improvement with a larger dataset in the future to extend the findings of this study. If possible, future studies should consider working on monthly data to obtain more robust results with a larger number of observations.

The second limitation was due to omitted variable bias. While this study utilized the Cobb-Douglas production function as opposed to the majority of the studies in the field that use bivariate models, adding variables such as R&D, FDI, and CO₂ would also offer valuable information and help better in evaluating the impact of renewables on the economy. For that purpose, an extension could be done by incorporating these variables in the follow-up studies.

And finally, the findings of this study cannot be generalized for other emerging countries since this research mainly relies on a single-country study. Thus, a further contribution of future studies should be improving the methodological design and increasing the number of countries investigated in a multivariate panel framework.

Nevertheless, despite these limitations, this study still offers some important policy implications for Turkey and its findings would be instrumental for decision-makers in guiding the country towards the path of low-carbon, sustainable, and climate-resilient economy in the future.

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Appendix A: VECM Granger Causality for short-run & long-run

$$\begin{aligned}\Delta \ln GDP_t &= \beta_0 + \sum_{i=1}^p \beta_i \Delta \ln GDP_{t-i} + \sum_{j=0}^{q_1} \beta_j \Delta \ln REC_{t-j} + \sum_{k=0}^{q_2} \beta_k \Delta \ln EC_{t-k} + \sum_{l=0}^{q_3} \beta_l \Delta \ln capital_{t-l} \\ &+ \sum_{m=0}^{q_4} \beta_m \Delta \ln labor_{t-m} + \delta_1 \ln GDP_{t-1} + \delta_2 \ln REC_{t-1} + \delta_3 \ln EC_{t-1} \\ &+ \delta_4 \ln capital_{t-1} + \delta_5 \ln labor_{t-1} + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta \ln REC_t &= \beta_0 + \sum_{j=1}^p \beta_j \Delta \ln REC_{t-j} + \sum_{i=0}^{q_1} \beta_i \Delta \ln GDP_{t-j} + \sum_{k=0}^{q_2} \beta_k \Delta \ln EC_{t-k} + \sum_{l=0}^{q_3} \beta_l \Delta \ln capital_{t-l} \\ &+ \sum_{m=0}^{q_4} \beta_m \Delta \ln labor_{t-m} + \delta_1 \ln REC_{t-1} + \delta_2 \ln GDP_{t-1} + \delta_3 \ln EC_{t-1} \\ &+ \delta_4 \ln capital_{t-1} + \delta_5 \ln labor_{t-1} + \varepsilon_t\end{aligned}$$

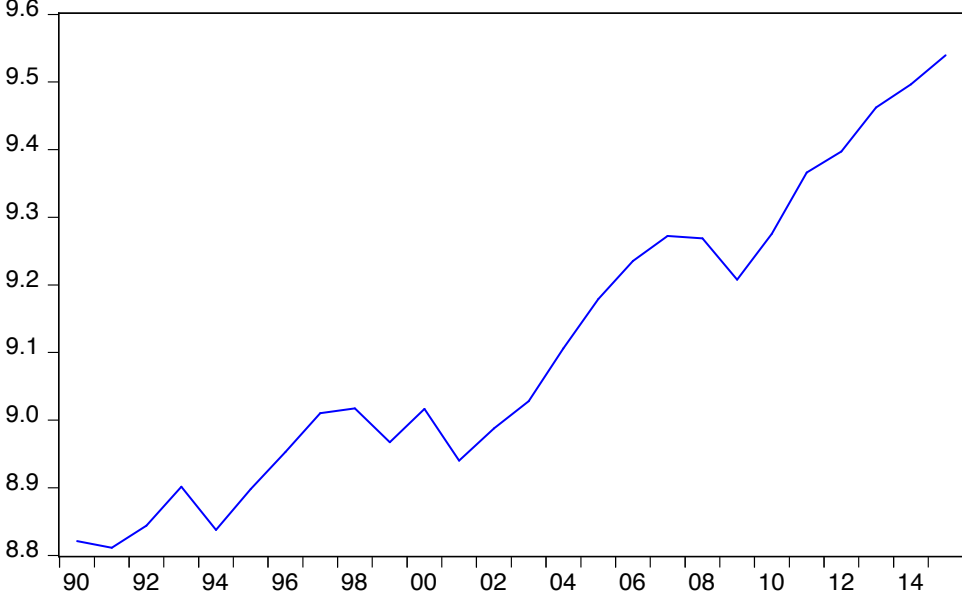
$$\begin{aligned}\Delta \ln EC_t &= \beta_0 + \sum_{j=1}^p \beta_j \Delta \ln EC_{t-j} + \sum_{i=0}^{q_1} \beta_i \Delta \ln GDP_{t-j} + \sum_{k=0}^{q_2} \beta_k \Delta \ln REC_{t-k} + \sum_{l=0}^{q_3} \beta_l \Delta \ln capital_{t-l} \\ &+ \sum_{m=0}^{q_4} \beta_m \Delta \ln labor_{t-m} + \delta_1 \ln EC_{t-1} + \delta_2 \ln GDP_{t-1} + \delta_3 \ln REC_{t-1} \\ &+ \delta_4 \ln capital_{t-1} + \delta_5 \ln labor_{t-1} + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta \ln capital_t &= \beta_0 + \sum_{j=1}^p \beta_j \Delta \ln capital_{t-j} + \sum_{i=0}^{q_1} \beta_i \Delta \ln GDP_{t-j} + \sum_{k=0}^{q_2} \beta_k \Delta \ln REC_{t-k} + \sum_{l=0}^{q_3} \beta_l \Delta \ln EC_{t-l} \\ &+ \sum_{m=0}^{q_4} \beta_m \Delta \ln labor_{t-m} + \delta_1 \ln capital_{t-1} + \delta_2 \ln GDP_{t-1} + \delta_3 \ln REC_{t-1} \\ &+ \delta_4 \ln EC_{t-1} + \delta_5 \ln labor_{t-1} + \varepsilon_t\end{aligned}$$

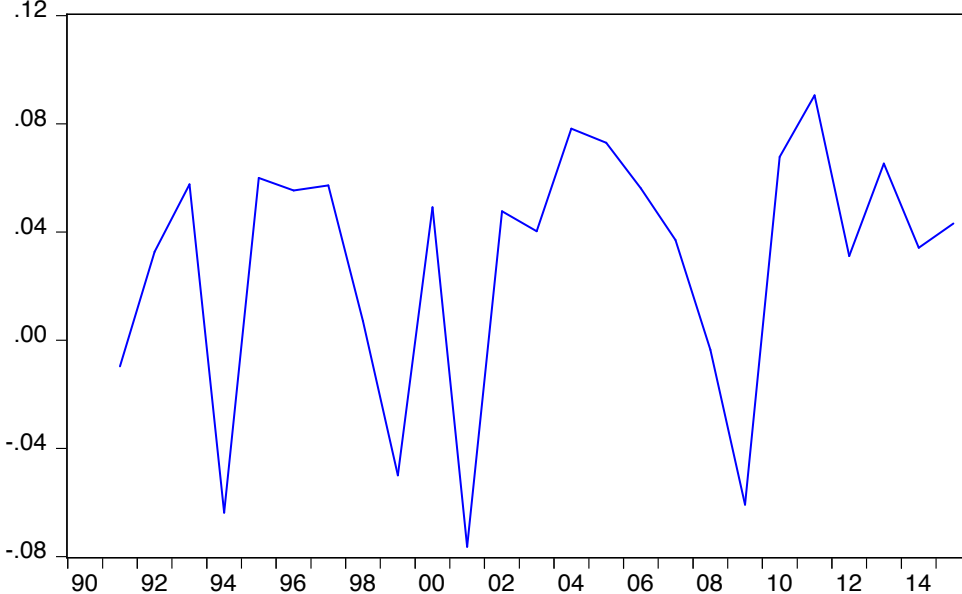
$$\begin{aligned}\Delta \ln labor_t &= \beta_0 + \sum_{j=1}^p \beta_j \Delta \ln labor_{t-j} + \sum_{i=0}^{q_1} \beta_i \Delta \ln GDP_{t-j} + \sum_{k=0}^{q_2} \beta_k \Delta \ln REC_{t-k} + \sum_{l=0}^{q_3} \beta_l \Delta \ln EC_{t-l} \\ &+ \sum_{m=0}^{q_4} \beta_m \Delta \ln capital_{t-m} + \delta_1 \ln labor_{t-1} + \delta_2 \ln GDP_{t-1} + \delta_3 \ln REC_{t-1} \\ &+ \delta_4 \ln EC_{t-1} + \delta_5 \ln capital_{t-1} + \varepsilon_t\end{aligned}$$

Appendix B: Non-stationary vs. Stationary series

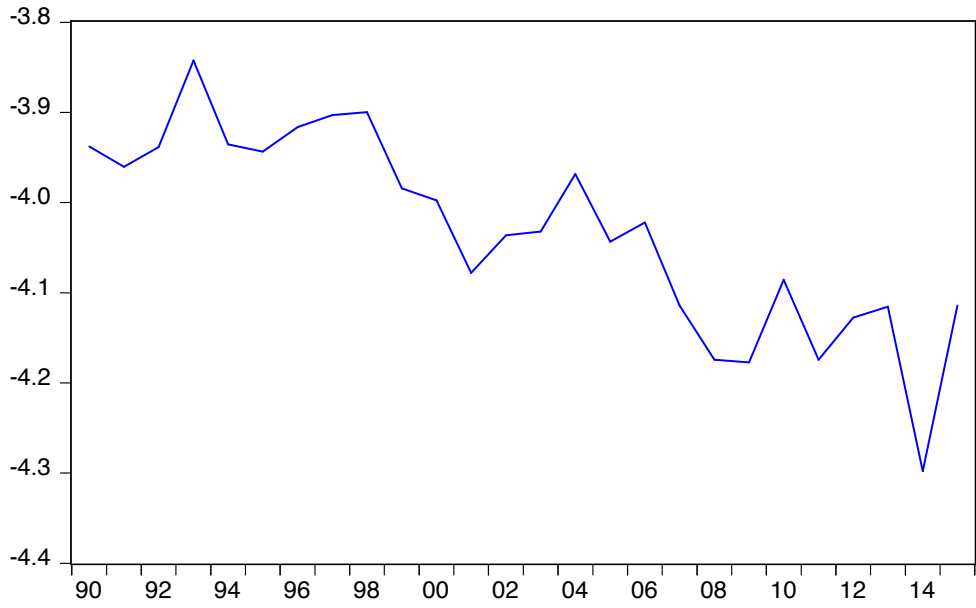
LNGDP



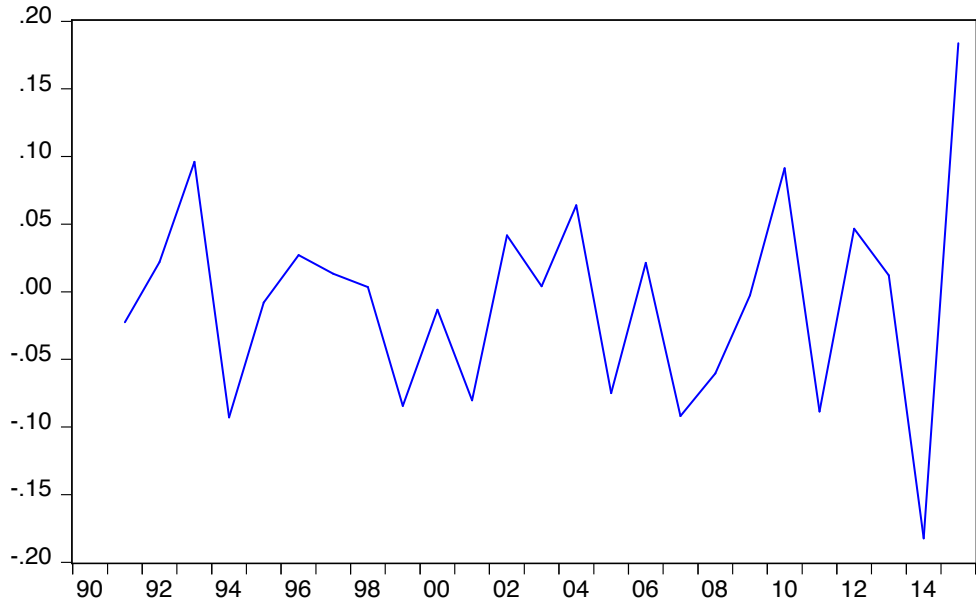
Differenced LNGDP



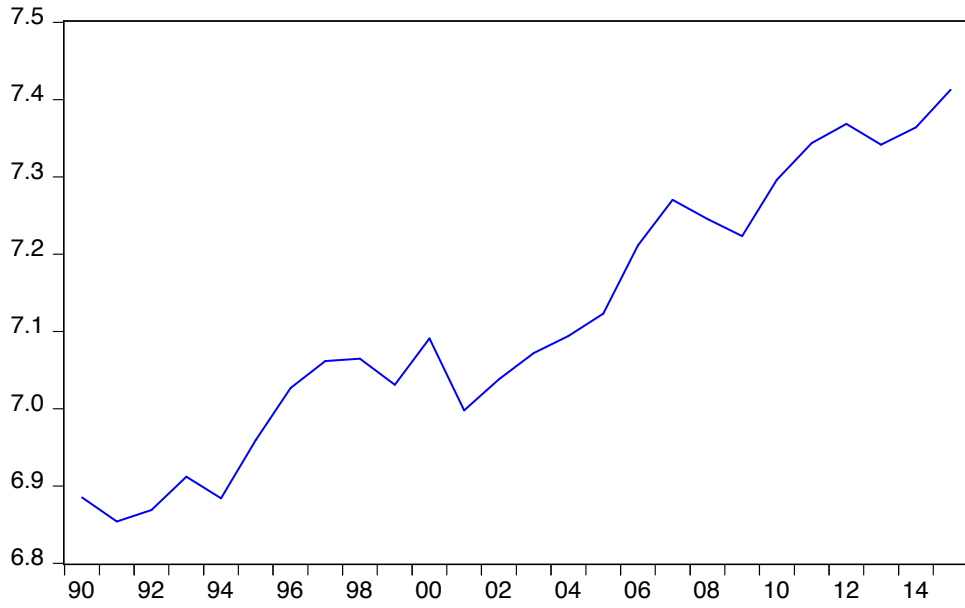
LNREC



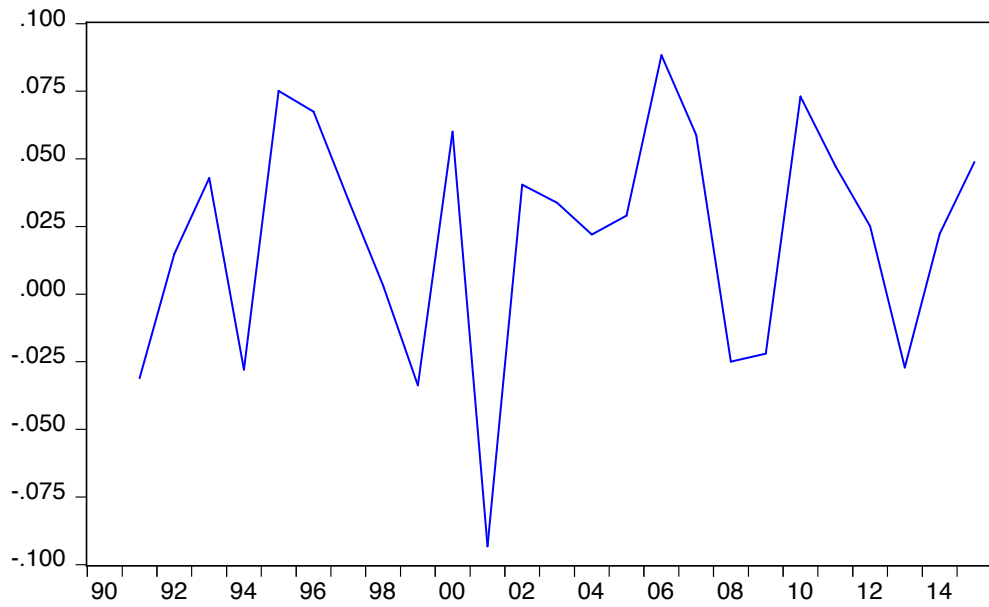
Differenced LNREC



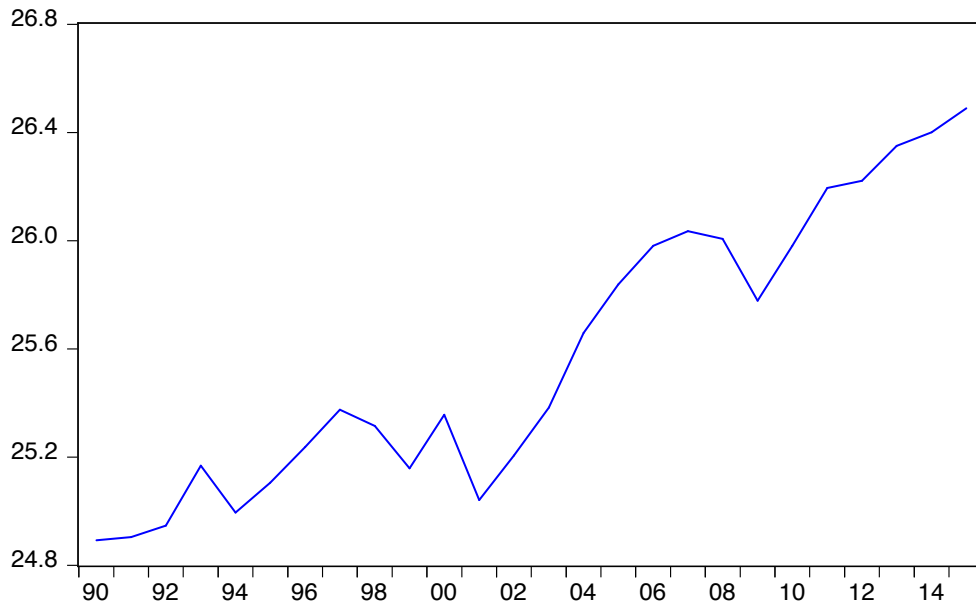
LNEC



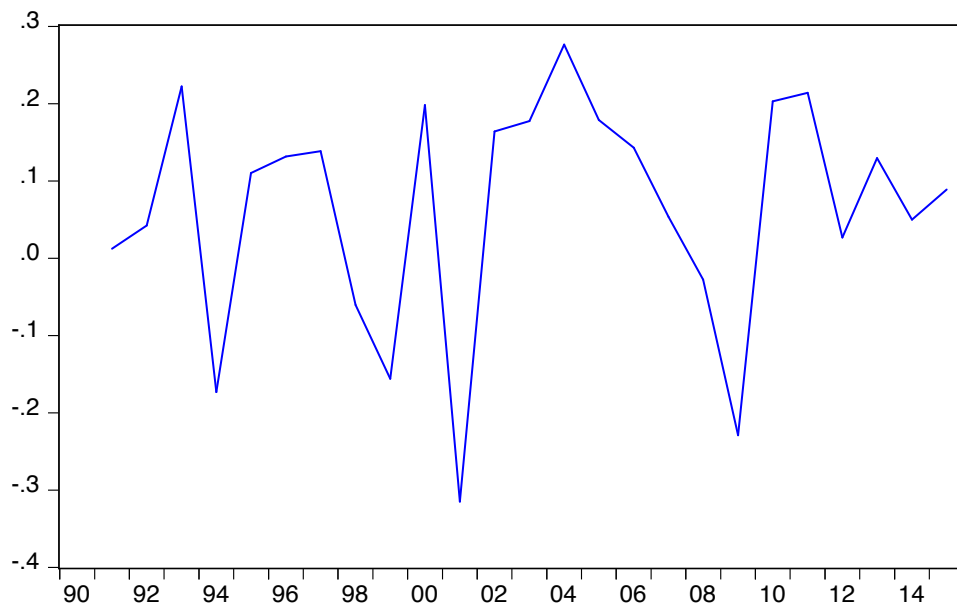
Differenced LNEC



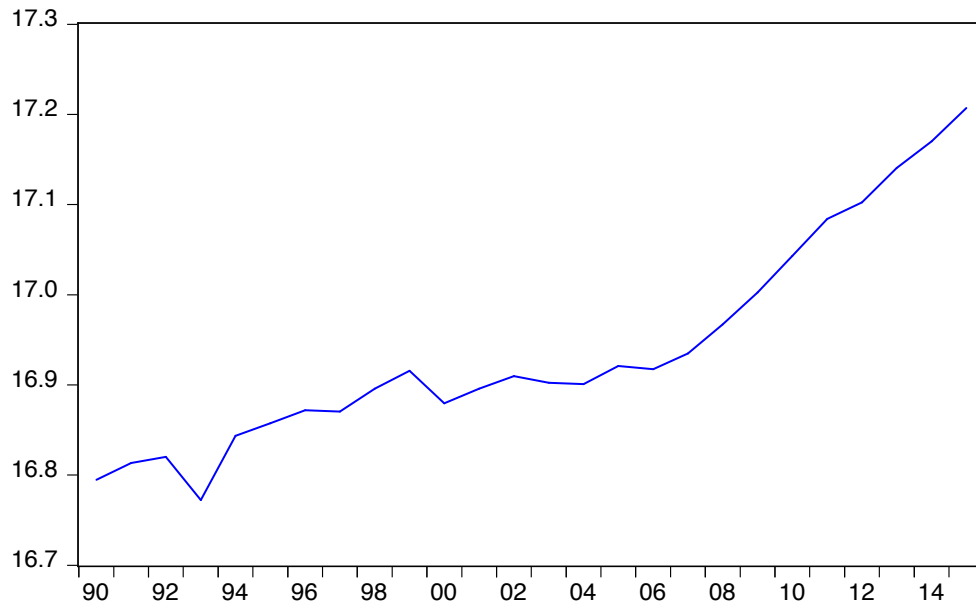
LNCAPITAL



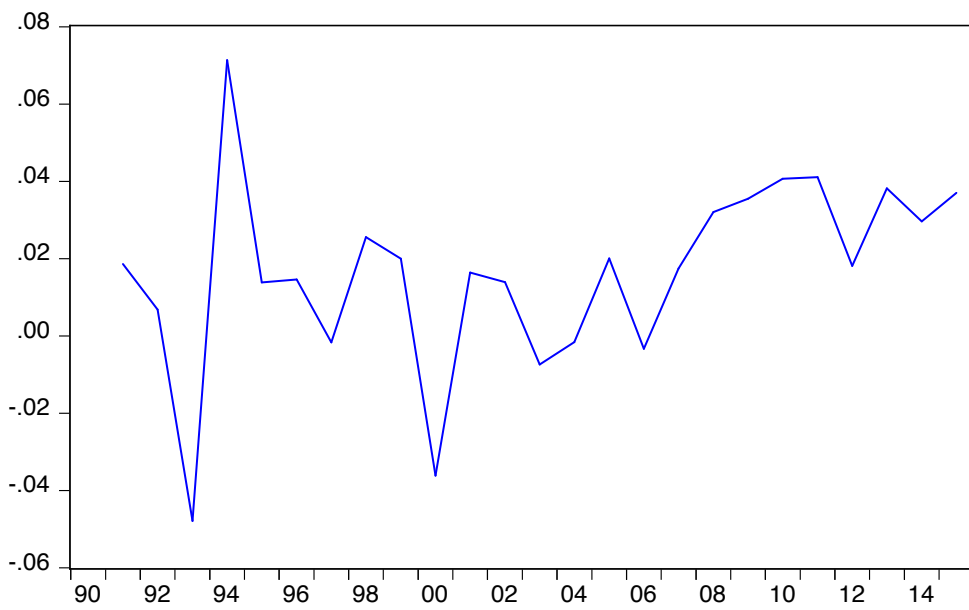
Differenced LNCAPITAL



LNLABOR

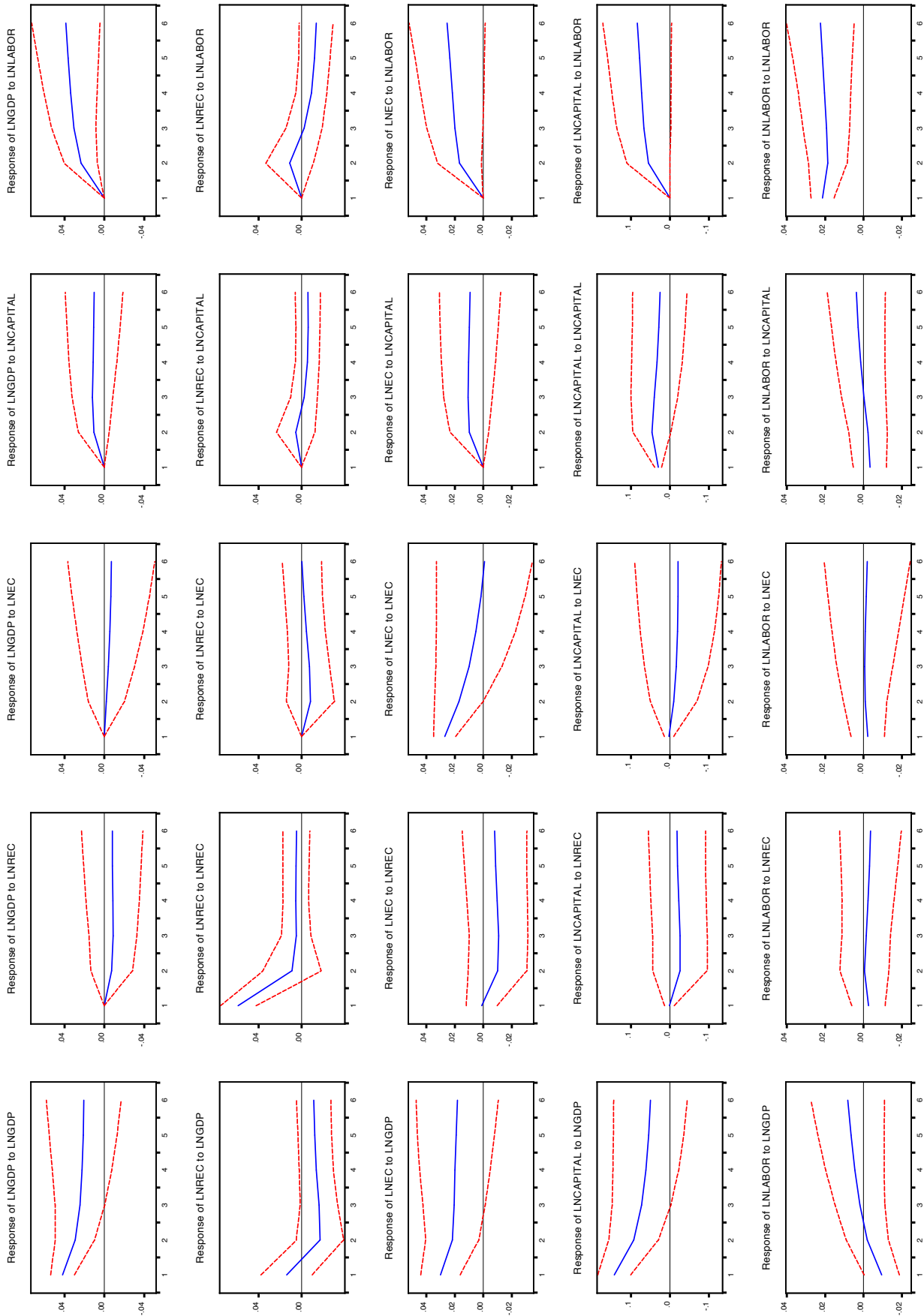


Differenced LNLABOR



Appendix C: IRF for all variables

Response to Cholesky One S.D. (d.f. adjusted) Innovations – 2 S.E.



Appendix D: VAR Decomposition results for all variables

Variance Decomposition of LNGDP:						
Period	S.E.	LNGDP	LNREC	LNEC	LNCAPITAL	LNLABOR
1	0.041897	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.057809	78.32264	1.609338	0.115358	3.377243	16.57542
3	0.071530	62.89519	2.548078	0.401358	4.983335	29.17204
4	0.083608	53.15076	2.903332	0.732896	5.486356	37.72666
5	0.094743	46.37230	2.996919	1.037979	5.544656	44.04814
6	0.105417	41.27210	2.983718	1.290892	5.429293	49.02399
7	0.115928	37.25019	2.929966	1.488814	5.250849	53.08018
8	0.126466	33.99015	2.864198	1.638241	5.057028	56.45038
9	0.137165	31.30198	2.798777	1.748345	4.868981	59.28191
10	0.148123	29.05958	2.738814	1.828051	4.695731	61.67782

Variance Decomposition of LNREC:						
Period	S.E.	LNGDP	LNREC	LNEC	LNCAPITAL	LNLABOR
1	0.060637	5.337017	94.66298	0.000000	0.000000	0.000000
2	0.065337	11.39845	83.41032	1.578038	0.683952	2.929235
3	0.067940	16.17862	77.68262	2.563149	0.743708	2.831909
4	0.070460	18.81438	72.81044	2.770242	1.271697	4.333233
5	0.072971	20.34477	68.40815	2.656934	1.846712	6.743436
6	0.075438	21.26739	64.41694	2.486804	2.305074	9.523796
7	0.077906	21.78691	60.72129	2.348957	2.641400	12.50144
8	0.080427	22.01630	57.23261	2.258811	2.881780	15.61050
9	0.083047	22.03551	53.89825	2.207978	3.051485	18.80677
10	0.085801	21.90524	50.68993	2.183546	3.170176	22.05110

Variance Decomposition of LNEC:						
Period	S.E.	LNGDP	LNREC	LNEC	LNCAPITAL	LNLABOR
1	0.040525	55.15750	0.076116	44.76638	0.000000	0.000000
2	0.053706	47.81157	3.548371	35.62679	3.334641	9.678632
3	0.063515	44.62106	5.409546	27.98261	5.233900	16.75289
4	0.071604	42.82286	6.101159	22.53187	6.196851	22.34726
5	0.078855	41.16682	6.240582	18.62241	6.651412	27.31877
6	0.085714	39.37965	6.122703	15.77037	6.804693	31.92259
7	0.092425	37.48309	5.887007	13.64033	6.774386	36.21519
8	0.099138	35.55582	5.603345	12.00281	6.635220	40.20281
9	0.105954	33.66725	5.307980	10.70426	6.435905	43.88461
10	0.112949	31.86523	5.019818	9.643767	6.207904	47.26328

Variance Decomposition of LNCAPITAL:						
Period	S.E.	LNGDP	LNREC	LNEC	LNCAPITAL	LNLABOR
1	0.146499	95.67262	0.009257	0.028837	4.289286	0.000000
2	0.189839	80.92324	1.860115	0.280403	8.483847	8.452393
3	0.220087	71.24978	2.765334	0.759162	9.641026	15.58470
4	0.244121	64.35576	3.079598	1.247165	9.712398	21.60508
5	0.265267	58.75882	3.149397	1.658193	9.397642	27.03595
6	0.285182	53.92866	3.120726	1.970360	8.943534	32.03672
7	0.304747	49.66631	3.053935	2.189964	8.449965	36.63982
8	0.324476	45.87715	2.975590	2.333437	7.961698	40.85213
9	0.344704	42.50152	2.897880	2.418723	7.499455	44.68242
10	0.365665	39.49371	2.826274	2.461716	7.072345	48.14596

Variance Decomposition of LNLABOR:						
Period	S.E.	LNGDP	LNREC	LNEC	LNCAPITAL	LNLABOR
1	0.023854	15.82761	1.179647	0.869998	1.947855	80.17489
2	0.030409	10.15800	0.752923	0.621106	1.810105	86.65786
3	0.036121	7.454108	0.683694	0.472852	1.285183	90.10416
4	0.041805	6.719601	0.839880	0.399935	1.093374	90.94721
5	0.047603	7.074336	1.084461	0.390286	1.179243	90.27168
6	0.053550	7.912001	1.331965	0.433153	1.403090	88.91979
7	0.059657	8.883992	1.547421	0.515186	1.671247	87.38215
8	0.065928	9.818571	1.722430	0.622514	1.934427	85.90206
9	0.072373	10.64585	1.859685	0.742997	2.171008	84.58046
10	0.079006	11.34800	1.965441	0.867267	2.374287	83.44501

Cholesky Ordering: LNGDP LNREC LNEC LNCAPITAL LNLABOR