COINTEGRATION AND CAUSAL EFFECT ANALYSIS BETWEEN ENERGY CONSUMPTION OF SECTORS AND THEIR CONTRIBUTIONS TO GDP GROWTH.

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ABSTRACT

COINTEGRATION AND CAUSAL EFFECT ANALYSIS BETWEEN ENERGY CONSUMPTION OF SECTORS AND THEIR CONTRIBUTIONS TO GDP GROWTH.

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There are plenty of studies conducted for the investigation of the long-run relationship between Energy Consumption and GDP growth of economies. Researchers applied cointegration and causality tests to aggregate Energy Consumption and aggregate GDP data of various countries at different time intervals. Some researchers have found a unidirectional causal effect between two variables, while others observed bi-directional causal effect. Almost all of them have observed the convergence. Since aggregate data constitute various sectors, previous studies analyzed the relationship between cumulative energy consumption of all sectors and cumulative product of the whole economy. However, structure of the economies evolve over time and contribution of each sector to the overall production changes. Analysis of the relationship between aggregate energy consumption and GDP data overlooks such factor along with many others like increase in energy efficiency. Gradual progress in technologies employed in each sector increased the productivity and reduced energy consumption. Therefore, in this study, the relationship between energy consumption in each sector of the economy and their corresponding contribution to GDP growth is investigated separately. Analysis shows that unlike in aggregate data results, sector-wise disaggregated data reveals divergence between variables though there is a cointegration and causal effect. This implies that conventional policy recommendations based on aggregate data cointegration and causal effect analysis are mis-guiding and there is a necessity for sector-wise tailored policies.

Keywords: Cointegration, Causal Effect, Sectoral Steady State

ÖZ

SEKTÖRLERİN ENERJİ TÜKETİMLERİ İLE GSYİH BÜYÜMESİNE KATKILARI ARASINDAKİ EŞBÜTÜNLEŞME VE NEDENSEL ETKİ ANALİZİ.

Gurbannyyazov, Arslan
Yüksek Lisans, İstatistik
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Enerji Tüketimi ile ekonomilerin GSYH büyümesi arasındaki uzun dönemli ilişkiyi araştırmak amacıyla pek çok çalışma yapılmıştır. Araştırmacılar, farklı ülkelerin çeşitli zaman dilimlerine ait toplam Enerji Tüketimi ve toplam GSYH verileri üzerinde eşbütünleşme ve nedensellik testleri uygulamıştır. Bazı araştırmacılar iki değişken arasında tek yönlü nedensellik tespit ederken, bazıları çift yönlü nedensellik gözlemlemiştir. Neredeyse hepsi yakınsama (convergence) gözlemlemiştir. Toplam veriler çeşitli sektörlerden oluştuğu için, önceki çalışmalar tüm sektörlerin kümülatif enerji tüketimi ile tüm ekonominin kümülatif ürününü birlikte analiz etmiştir. Ancak zamanla ekonomilerin yapısı değişmekte ve her sektörün toplam üretime katkısı farklılaşmaktadır. Toplam enerji tüketimi ve GSYH verileri arasındaki ilişkinin analizi, enerji verimliliğindeki artış gibi bu tür faktörleri göz ardı etmektedir. Her bir sektörde kullanılan teknolojilerdeki kademeli ilerleme, verimliliği artırmış ve enerji tüketimini azaltmıştır. Bu nedenle bu çalışmada, ekonominin her bir sektöründeki enerji tüketimi ile bu sektörlerin GSYH büyümesine katkısı arasındaki ilişki ayrı incelenmektedir. Analiz, toplam verilerden elde edilen sonuçların aksine, sektörel olarak ayrıştırılmış verilerin değişkenler arasında eşbütünleşme ve nedensellik olsa da bir ayrışma (divergence) ortaya koyduğunu göstermektedir. Bu da, toplam veriler üzerinden yapılan eşbütünleşme ve nedensellik analizlerine dayalı geleneksel politika önerilerinin yanıltıcı olduğunu ve sektörel düzeyde uyarlanmış politikalara ihtiyaç duyulduğunu göstermektedir.

Anahtar Kelimeler: Eşbütünleşme, Nedensellik, Sektörel Denge Durumu

To my mother and grandfather.

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LIST OF ABBREVIATIONS

ABBREVIATIONS

GDP: Gross Domestic Product

TFEC: Total Final Energy Consumption

GDPPC: Gross Domestic Product per Capita

TFECPC: Total Final Energy Consumption per Capita

ICPC: Industrial Sector Energy Consumption per Capita

SCPC: Services Sector Energy Consumption per Capita

OCPC: Other Sectors Energy Consumption per Capita

TCPC: Transports Energy Consumption per Capita

RCPC: Residential Energy Consumption per Capita

IGDPPC: Industrial Sector’s Share of GDP per Capita

SGDPPC: Services Sector’s Share of GDP per Capita

OGDPPC: Other Sector’s Share of GDP per Capita

GJ: Giga Joules

PJ: Penta Joules

LIST OF SYMBOLS

SYMBOLS

A: Level of Technology

C: Consumption

D: First Difference of Variable

I: Inverstment

G: Government Expenditure

NX: Net Exports

K: Accumulated Capital

L: Labor

Y: Total Output or GDP

y: Total Output or GDP per Capita

k: Accumulated Capital per Capita

Δ: Differece

CHAPTER 1

INTRODUCTION

Cointegration and causality analysis methods are widely used in Economics and Finance for the investigation of long-run relationships between many time-series variables. One of the study areas where cointegration and causal relation analysis applied is the relationship between energy consumption and the GDP growth. Many studies showed that there is a cointegrating relation between those variables and also there is a causal relation running from one variable to another. Findings indicated that energy consumption leads to GDP growth, GDP growth leads to energy consumption though there is a previous work indicating that there is no such effects. In almost all of those studies, researchers employed aggregate total energy consumption data of countries either in prime or final total energy consumption form and aggregate annual GDP data. In this study, total final energy consumption data (TFEC) and annual GDP of countries at constant 2015 USD (GDP) data disaggregated into sectors and cointegrating and causal relations are investigated both at aggregate level and disaggregate sectoral level.

1.1 Gross Domestic Product – GDP and Energy Consumption

Gross Domestic Product – GDP is the sum of monetary values of all final products and services produced by the entities within the borders of the country, sold within the borders and abroad. All exported goods and services are accounted in the GDP, while imported goods and services are excluded. Hence, it is a precise indicator of production capability and capacity of countries. Though there are cases of unaccounted production and sales of goods and services in almost all countries, GDP data compiled and provided to the international organizations considered as a true indicator of economic activities.

In order to avoid double counting, raw materials and intermediary goods that are used as inputs to produce final goods not recorded in the GDP since they are embedded in the values of final goods. For example, milk produced and sold to the consumer is accounted in GDP, while milk produced and sold to the cheese factory is not recorded. Similar accounting and recording method applied to the energy sources also. Since energy sources like coal, oil, gas and electricity sold to the firms used for producing goods and services, they are also not included in the GDP as a separate item line since they are accounted in the price of final products. However, energy sources sold to the consumers for heating their homes, cooking, lighting, running electrical appliances or moving their vehicles are accounted in the GDP because they are sold as final products. Therefore, in order to understand the purpose of energy consumption and its contribution to the GDP, Energy Consumption and GDP data should be disaggregated and analyzed separately.

Form the production perspective, GDP is disaggregated as industrial sector GDP, services sector GDP and other sectors GDP according to their shares in GDP. Industrial sector GDP includes values of all final manufactured goods, construction and mining activities. It is the largest energy-consuming sector in many countries. Other sectors GDP constitutes final products sold to consumers from agricultural activities, forestry and fishing. In developed countries, it represents only small share of aggregate GDP. Unlike other sectors GDP, the largest share of aggregate GDP comes from the services sector in the developed countries and in the majority of developing countries. Though it represents largest share of aggregate GDP, energy consumption in the Services Sector is far below than in the Industrial Sector. It is mainly because Services Sector includes entities that are involved in activities like education, health services, banking services, tourism and etc. where low energy consuming equipment and appliances are used. It worth to note here that energy consumed by transports is accounted separately and might have some negative effect in correct calculations of energy consumed by industrial, services and other sectors.

Since largest share in transports energy consumption belongs to the passenger cars, and due to the difficulty in attributing energy consumed by transports to each specific sector, transports energy consumption kept as a separate variable.

From the consumption perspective, GDP can be disaggregated as Consumption, Investment, Government Expenditure and Net Exports. Households, firms and government or foreign buyers acquire all final goods and services produced by the countries. Energy consumed by households at their homes and for driving their vehicles is accounted in Consumption part of the GDP. Durable goods like buildings, vehicles and equipment purchased by households, private and public entities, are recorded in the Investment part of the GDP. Hence, it can be said that while Consumption part of GDP is related with current period energy consumption, Investment part of the GDP is related with both current period and future periods since the Investment of current period affects energy consumption values of the future periods.

In fact, insight for cointegrating and causal relation between energy consumption and GDP data analysis arose from the fact that current Investment level of GDP affects the future energy consumption level. However, GDP presents only the monetary value dimension of the Investment. It does not provide any other information about the physical and technological properties of the durable goods accumulated for future. Detailed information about the properties of accumulated durable goods can provide much clearer vision about how energy consumption would be affected.

Economists argue that GDP of countries would grow till a level where it would stay for a long period of time unless there is a change in technology. Such level is defined as a Steady State. In the Steady State, Investment of current period is just sufficient to recover the depreciated portion of accumulated physical capital and to maintain the same level of output for the increase in the population. If such level exists, intuitively, energy consumption level also should reach to the steady state if there is no technological change that would increase the energy efficiency and decrease energy consumption.

In practice, aggregate GDP and energy consumption values of countries usually reveal increasing pattern. That is why many researchers interested in analyzing the cointegrating relationship and causal effect between energy consumption and GDP. However, on the other hand, there is a continuous increase in energy efficiency of equipment and appliances used in the economy that has a decreasing effect in energy consumption. Moreover, a continuous population growth increases the demand for more goods, services and energy sources. For instance, in the Figure 1.1, TFEC, GDP and Population of France for a period 1971-2019 reveal that there is continuous growth in Population and GDP. However, TFEC growth continues till 2005 and then starts declining. Figure 1.1 also presents that there is a high possibility of cointegrating relationship between TFEC and GDP variables between the period 1982-2005.

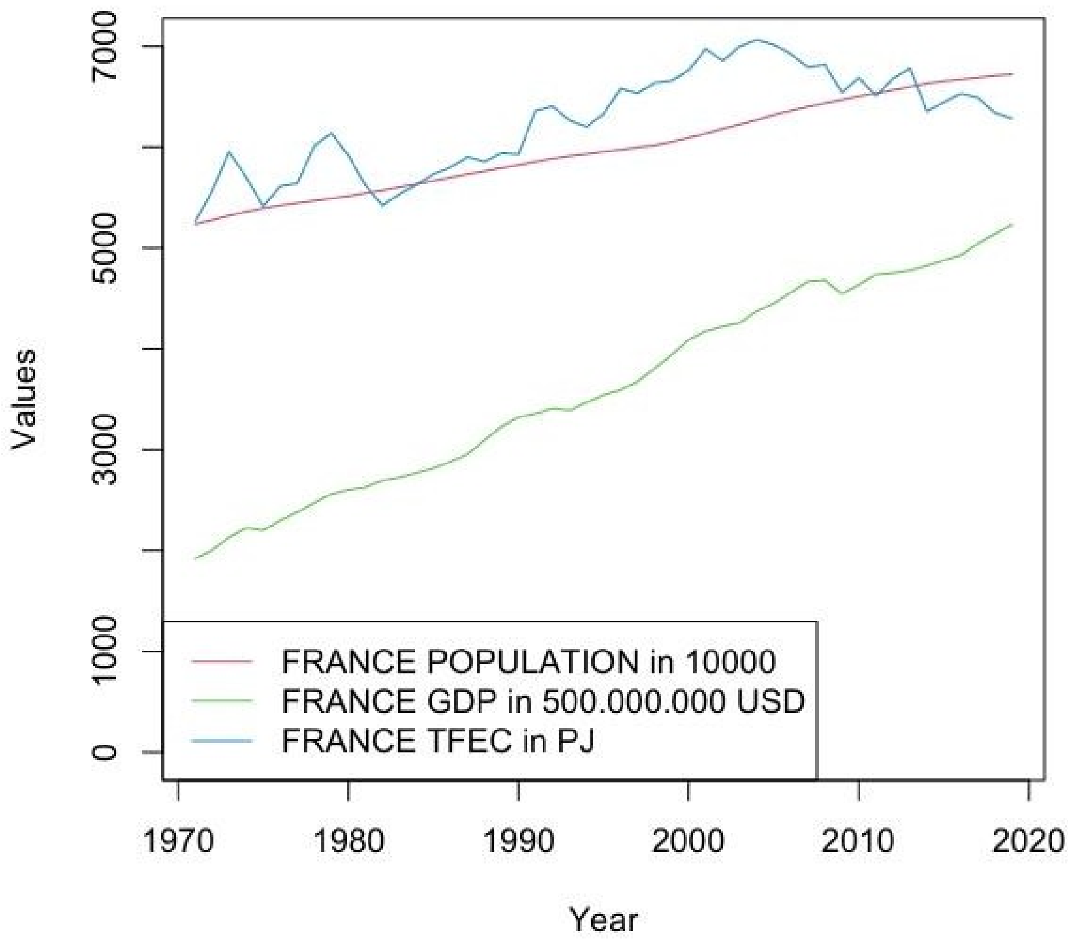

Figure 1.1 France Population, GDP and TFEC in PJ

While Figure 1.1 reveals the possibility of cointegrating relationship between TFEC and GDP variables, Figure 1.2 reveals that there are no stochastic trends between GDP and TFEC series of United Kingdom. Figures 1.1 and 1.2 for provide a hint that TFEC and GDP series of developed countries might reveal different trends, and follow opposite direction paths due to the efficiency effect in TFEC. Moreover, they demonstrate that there might be differences in the trends of subject variables among the developed countries depending on how and where energy sources are utilized. For example, Switzerland might be using energy sources mainly in high-tech product manufacturing while Norway is using energy for producing energy intensive chemical products.

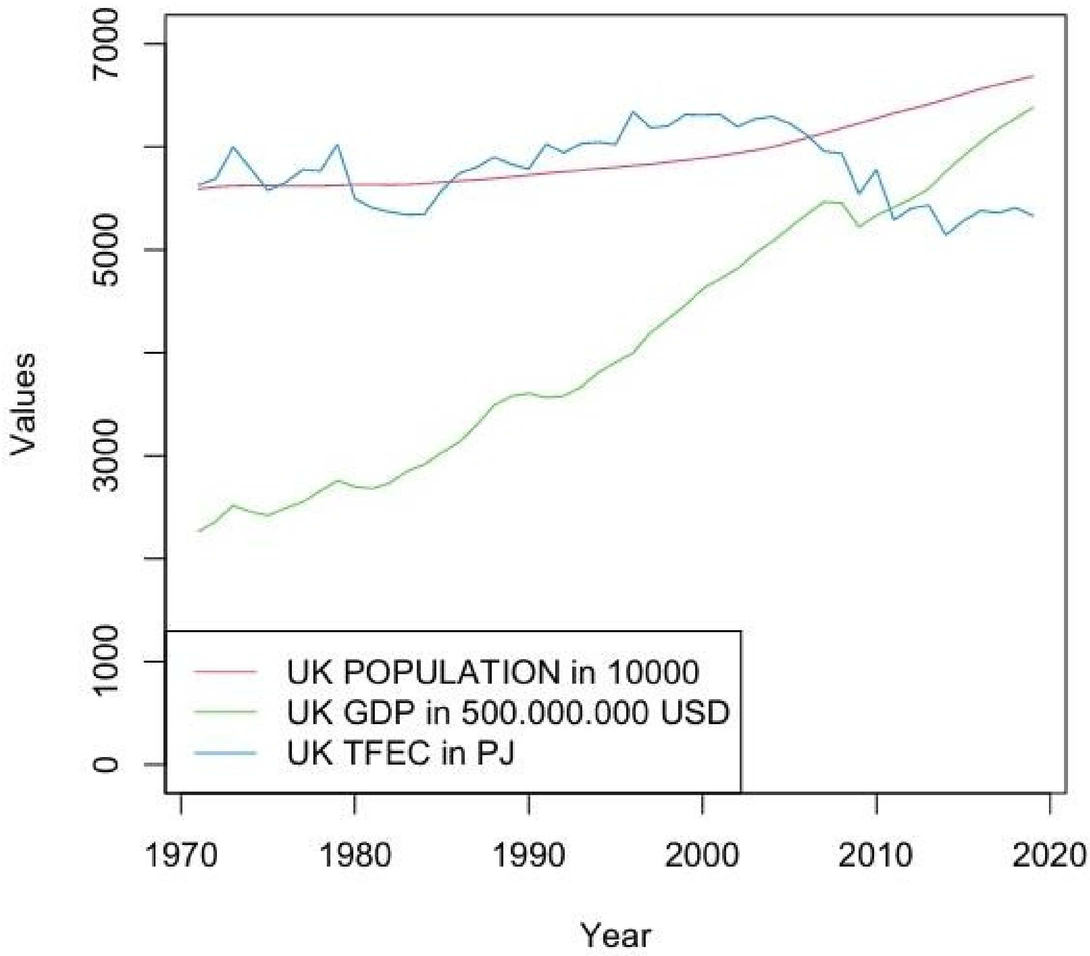

Figure 1.2 United Kingdom Population, GDP and TFEC in PJ

Unlike in developed countries, TFEC and GDP series reveal similar trends and paths in developing countries. As can be observed from the Figure 1.3, TFEC for South Africa would continue to be much above the GDP at least in a medium-run. There is no tendency in GDP to catch the level of TFEC. It might be because South Africa is positioned at the bottom of a supply chain, and produces mainly raw material or intermediary goods for the industries of developed countries. Unless it increases the share of investment in medium-tech and high-tech industrial production or finds energy efficient technologies to replace existing technologies in the economy, energy consumption series might stay above the GDP series for a long period.

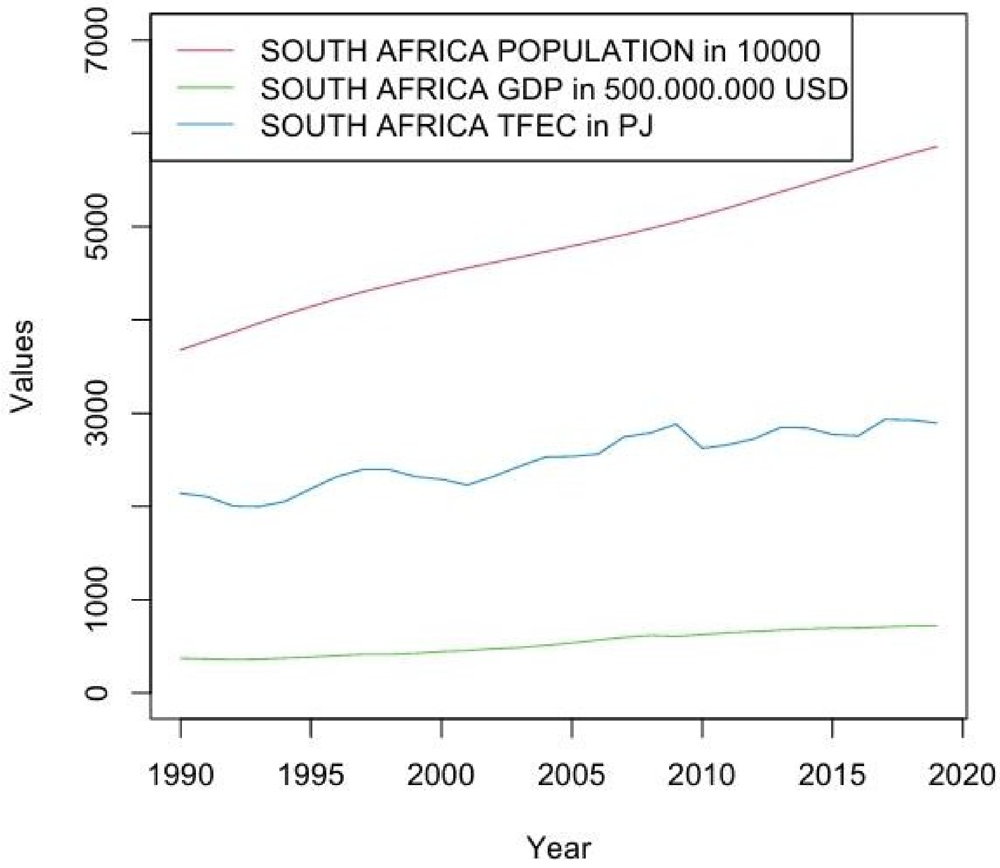

Figure 1.3 South Africa Population, GDP and TFEC in PJ

1.1.1 Energy Efficiency Effect in Energy Consumption

Energy efficiency is a progress in a quantity of a task accomplished by using the same unit of energy. In other words, it is producing more goods and services with the lower energy requirement. Throughout the history, humanity always thrived to accomplish more tasks and jobs with less human labor, less tools and less energy sources. Since industrial revolution, humanity recorded huge progress in that objective. Starting from that revolution, energy efficiency increased in unimagined rate. It altered previous economic, social and political structure of the old world and constructed a new era where a simple equipment can accomplish the task that required thousands of horses and human labor two centuries ago.

Majority of the equipment, machinery, appliances and tools used for production of goods and services in the economy has limited useful life. Throughout their useful life they are depreciated. Thus, they require either maintenance or replacement. Depreciated machinery, equipment and appliances are replaced with the new ones that are usually more energy efficient models. Besides, commercialization of new inventions require new machinery, factories, buildings that in turn require more energy. Invention of automobiles, trains, airplanes and many other machinery leaded to the establishment of new factories or even to the development of special industrial zones. Till the mid-20^{th} century, though there was a significant continuous improvement in energy efficiency, energy consumption continued to increase. It was mainly due to the increase in the machinery and equipment used by the economies. In other words, increase in energy to run the accumulated physical capital outweighed the effect of energy efficiency.

By the emergence of electronics sector in 1950s, and later commercialization of computers and internet, the leading economies of the world started to specialize their economies in more value adding products and services. New investments in low technology and energy intensive productions started shifting to the less developed countries. For instance, starting from 1980s, there was a continuous and increasing shift of production from developed countries to China and surrounding countries. Moreover, collapse of the Eastern Block in 1990, leaded to further production shift from western developed countries to the east. Since then, there is a decrease in industrial sector energy consumption levels of many developed countries while there is an opposite direction pattern in developing countries.

Similar to industrial sector energy consumption, in many developing countries, there is a continuous increase in transports energy consumption, residential energy consumption and services sector energy consumption levels. Such pattern is associated with the increase in the Consumption level of households in developing countries and their Investment decisions. For instance, increase in GDP of developing countries enables households to purchase home appliances, to demand more public and private services, and to buy private vehicles. All those purchasing decisions increase the energy consumption in developing countries. Since accumulation of all energy consuming machinery, equipment, appliances and vehicles would continue until they reach the levels at developed countries, effect of energy efficiency in those countries is not observed.

1.1.2 Energy Consumption and GDP Per Capita

Energy consumption and GDP values of countries do not provide the clear picture about economic conditions of the countries. For instance, GDP and energy consumption values of India are much higher than the corresponding values of many developed countries. However, when both values are divided by population, India is far behind than all of the developed countries. In fact, not total GDP and energy consumption data, but their per capita levels correctly provide their development status. Moreover, per capita disaggregated values of energy consumption and GDP provide the level of development in each sector individually. It enables comparison of sector-wise energy consumption and GDP values of countries in a more precise way. For example, GDP per capita (GDPPC) and total final energy consumption per capita (TFECPC) values of two countries can be at the same level in a given year, but distribution of the values among the sectors might be very different. Thus, policy recommendations based on aggregate data, even at a per capita level, might mis-guide the growth of the economy. Figures 1.4 and 1.5 clearly demonstrate that in 2000 TFECPC of Australia (156 GJ) and Netherlands (152 GJ) are close to each other, but the distributions of TFECPC values among sectors are very different. Hence, policies that would be powerful in enhancing economy of Netherlands might be harmful if applied to Australia.

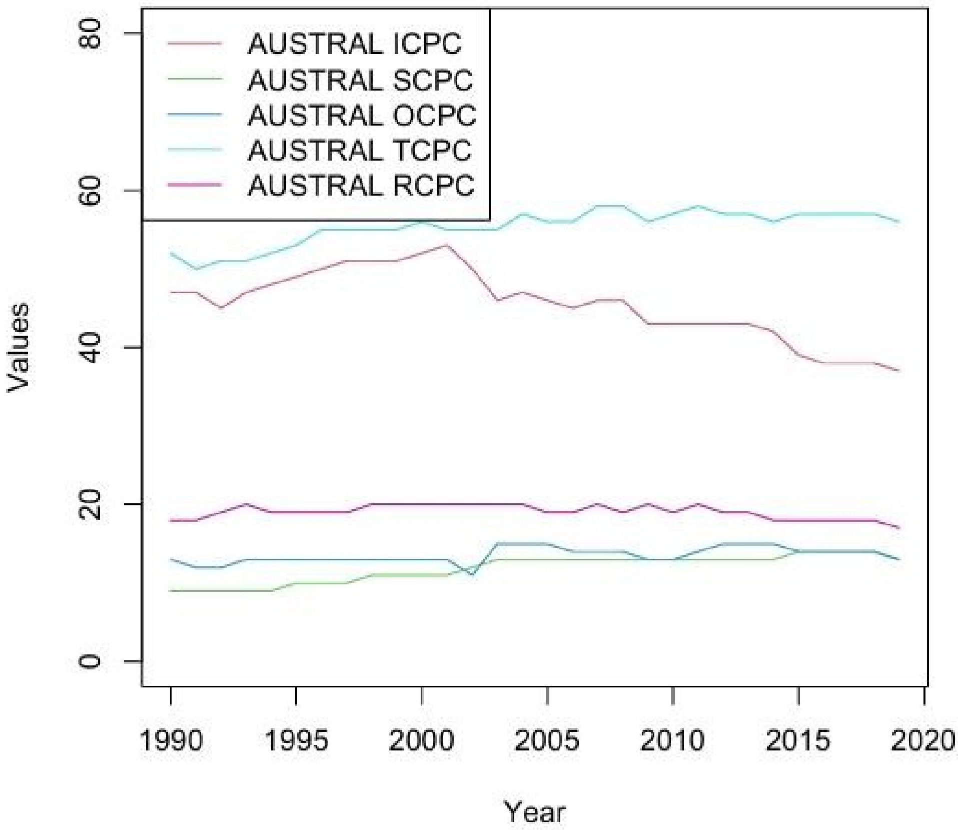

Figure 1.4 Australia Sector-wise Disaggregated TFECPC

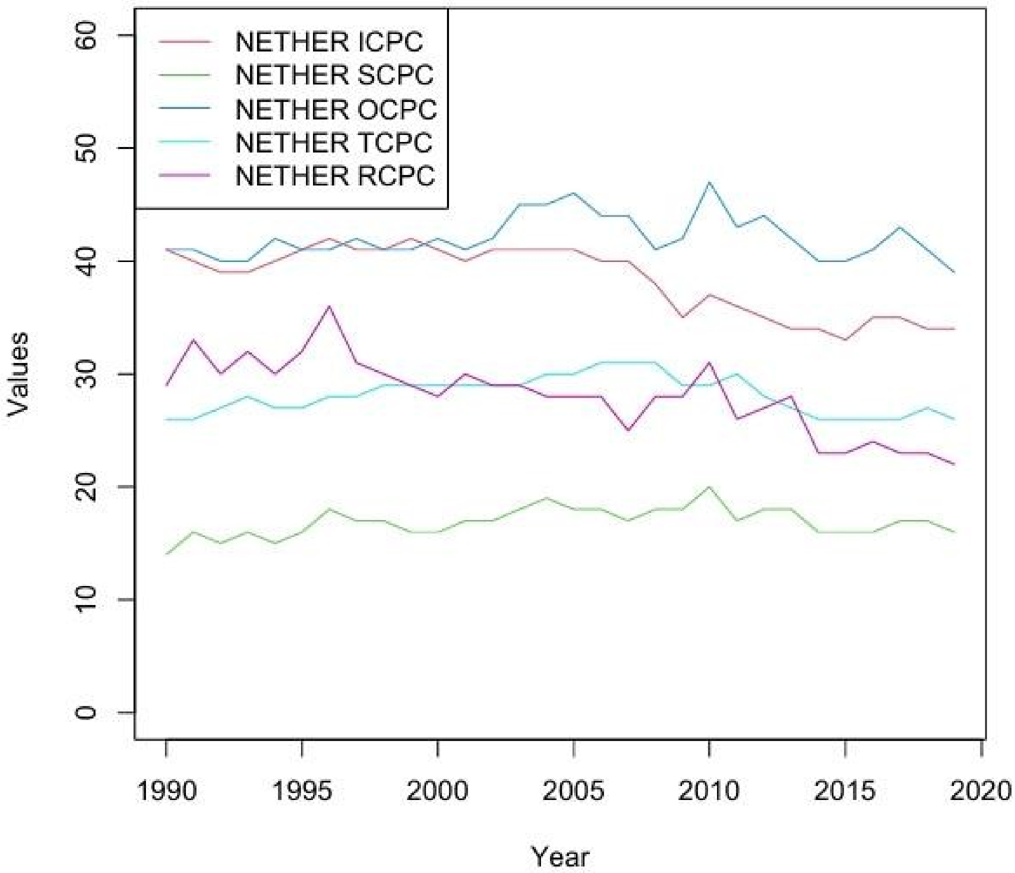

Figure 1.5 Netherlands Sector-wise Disaggregated TFECPC

However, for a long period of time, researchers are employing aggregate energy consumption and GDP data to analyze cointegrating and causal relationships beween them in order to formulate their policy recommendations. For instance, through analyzing aggregate data of countries, Soytaş & Sarı (2003) argued that the energy conservation policies would harm in the long-run the GDP growth of France, Germany and Japan. However, Figure 1.1 reveals that GDP growth continued in France though there is a decline in TFECPC most probably as a result of energy conservation policies. Similar pattern observed also in Germany, Japan and other developed countries.(see Appendix F for countries with decreasing TFEC and increasing GDP)

Currently many developed and developing countries are working on policies that would reduce CO_2 emissions from energy consumption. Kyoto Protocol that was adapted in 1997 and entered into force in 2005 aimed reducing CO_2 in industrialized countries, followed with Paris Agreement, which aims to mitigate global warming, signed by majority of United Nations member countries in 2016. Since then, many countries adopted CO_2 emission reducing legislations and announced targets. However, since CO_2 emission mainly sourced from the conventional energy sources, industries where they are heavily used, there is a debate that CO_2 emission reducing policies might adversely affect some industries and economies. Cointegration studies conducted between energy consumption and GDP studies should be useful in shedding a light for setting correct policies that would both enable to achieve persistent GDP growth and to hit the CO_2 emission target. In fact, the aim of this study is to contribute to researchers and policymakers for paving correct pathways in accomplishing that task.

CHAPTER 2

LITERATURE REVIEW

Application of mathematical and statistical tools to the social sciences require careful surveillance. Robinson (1964) stated that application of scientific methods to social sciences is difficult, because there are no established and agreed standards for disproving the hypothesis. However, as a leading user of mathematical and statistical tools among the social sciences branches, the economics discipline cannot analyze the economic environment, develop theories and test hypotheses without such tools. Robinson (1964) highlighted the importance of those tools in the development of economics, as "Economics is not only a branch of theology. All along it has been striving to escape from sentiment and to win for itself the status of a science". In fact, Robinson is neither the only nor the first economist who highlighted this point. As early as in late 19th century Jevons (1888) attributed importance to such tools with the following statement: "It is clear that Economics, if it is to be a science at all, must be a mathematical science".

2.1 Ordinary Least Squares and Econometrics

The most important statistical tool employed in economics is the ordinary least squares (OLS). Its application in economics is so wide that it lead to the birth of a sub-branch in economics called "Econometrics". The role of OLS is so essential in economics that without OLS, majority of the economic theories cannot be even tested. Moreover, OLS employed in economics as an initial clue to find evidence leading to the construction of new theories. As Robinson (1964) noted "The function of economic theory, as opposed to economic theology, is to set up hypotheses that can be tested". However, nowadays, the mainstream in economics is to reach theory from empirical evidence. In most of the cases, OLS results play an essential role as "evidence" to construct the theories and policies. Unfortunately, their role in setting policies is more perilous than constructing theories, due to implementation and their possible adverse consequences. In earlier periods, economists approached to the OLS results with suspicion. For instance, Robinson (1964) noted as "Keynes was very skeptical of econometrics (it is by no means certain that the work done in the last twenty years would have laid his doubts); but it was he who made the new statistical work possible." Nowadays, the results of OLS are used with reliance and credit.

Problem is not in OLS itself, but in its application in econometrics. Unlike in statistics, where OLS results are used to quantify the level of association between variables, in econometrics it is used to observe the causal relation and direction of such associations. For instance, Orcutt (1952) described importance of observing causal relation and direction, as "There are three essential reasons why, in seeking to discover the impact of actions, we should look for causal relations. First, as emphasized in a preceding paper, the policy implications of any relation depend critically upon whether it holds in one or more directions".

2.1.1 Causal Relation

Since many variables in economics are interdependent, quantifying the level of association between them is not sufficient for economists. Therefore, as early as in 1950's, econometricians Orcutt (1952) and later Koopman (1953) introduced the "causal relation" by the assistance of Simon (1952) from philosophy field who constructed the formal definition of "causal relation" for econometricians. Following the studies of Granger (1963;1967) who proposed empirical method for testing the causal relations, econometricians started widely searching for causal relations between interdependent variables to propose policies or to evaluate the possible consequences of them. On top of those testing methods, the introduction of cointegration and error correction models by Granger (1981), Granger & Weiss (1983), Granger (1986), Engle & Granger (1987) enabled more sophisticated tools to analyze causal relations to the between interrelated time-series variables.

One of the areas where causal relations widely investigated is the relation between GDP and energy consumption. Though in earlier periods there were some sparky studies on that subject, oil supply crises of 1973 ignited investigations so flamingly that the flare of such studies is still ongoing. While Kraft & Kraft (1978) found unidirectional causal relation from GDP to energy consumption and favored Energy Conservation Act of 1975, Akarca & Long (1980) refuted their results through extending the time-series period by two more years. Findings of Yu & Choi (1985) supported the argument of Akarca & Long (1980) for the United States data. However, their studies showed various causal relation results for other countries.

2.1.2 Cointegration

Just after the introduction of co-integration by Engle & Granger (1987), Nachane et al. (1988) employed co-integration and causality tests to observe the direction of causal relation between GDP and energy consumption and found varying results. Since then, hundreds of studies are conducted to analyze co-integration, detect the direction of causal relation between them. Findings vary from bi-directional causal relation to no causal relation. Studies are concentrated around four hypotheses: Conservation, Growth, Feedback and Neutrality. Bouoiyour et al. (2014) tabulated results with hypothesis types found by many researchers for different countries and periods. Similar table was presented by Inglesi-Lotz and Morales (2017) for various studies. Tables of both studies show that the results vary and reveal all four hypotheses.

Almost in all those studies, researchers employed aggregate GDP and aggregate energy consumption data. However, as early as in 1950s when the definition of causal relation for econometrics was formulated, Orcutt (1952) highlighted importance of disaggregated data in studying the causal relations as “Our position then is that, while making all possible use of aggregate time series, we must nevertheless place our main hopes for the determination of causal relations upon less aggregative data”. Therefore, in this study, sector wise disaggregated energy consumption and GDP series of various countries are employed. Moreover, sector-wise energy efficiency variables are included to investigate cointegration, causality, patterns of convergence & divergence between them. Despite the fact that studies of Goldemberg et al. (1987), Flawin & Durning (1988) were clearly showing considerable sector-wise energy efficiency improvements, and expectations of Goldemberg et al. (1987) were that per capita energy consumption would fall by 50% between 1980-2020, energy efficiency was disregarded in the previous studies.

2.2 Energy Efficiency and Energy Consumption

Energy efficiency is the capability of more wisely directing the force created by a power source to the task intended to be fulfilled. Such wise way of performing it awarded cost efficiency and competitiveness throughout the history. However, when the energy sources are abundant and cheap, directing efforts to the energy efficiency do not pay desired rewards. Hence, under such conditions improvements in energy efficiency is disregarded unless there is a sudden shock in the energy prices. Around half century ago, energy price shock created by oil producing countries apparently demonstrated importance of energy efficiency. By the effect of that price shock, hesitant political actions towards improving the energy efficiency that were initiated before the shock gained wide support from public and private sectors. Since the major energy consumers of the world were the developed western countries, energy conservation policies followed by immediate action in those countries. As early as in 1977 Economic Cooperation for Europe (ECE) member countries held a seminar stressing the necessity of immediate actions on coordinated energy conservation policies (United Nations Centre for Human Settlements, 1991). Those efforts payed remarkable results. According to the same report, in developed countries like USA, Germany, Belgium, Italy, Netherlands and Luxembourg total and per capita energy consumption were lower in 1986 compared to 1980.

Major improvements were in industrial and residential sector energy consumptions while demand for energy in transportation sector continued to grow due to the increase in number of vehicles. Though energy efficiency in Transportation Sector were apparent at per vehicle level, total energy consumption of the sector in western countries projected to grow until 1990s, where sector largely dependent on road transportation (United Nations E/ECE/61, 1978). Moreover, in US which consumed largest share of the world oil production, per vehicle fuel consumption in new models increased mainly due to the weight increase from 1965 to 1975 (Hurter et al., 1974). As a result, in 1978 road vehicles were consuming 82.5% of the total fuel used in transportation sector (Automobile Fuel Economy Program, 1980). That undesirable situation in car fleets required immediate action. Therefore, US imposed new standards for the new model cars where mile per gallon of fuel has to be increased to 18 in 1978 and to 27 in 1984 (Report CED-77-107, 1977). Additionally, US increased public awareness about the fuel economy to encourage them to shift to more fuel-efficient vehicles. Policies were effective and results showed that though mileage driven by vehicles increased significantly from 1983 to 1985, increase in the total fuel consumption of vehicles was very low (Report DOE/EIA-0464(85), 1987). Besides, compared to 1974 level, total fuel consumption by personal passenger vehicles was lower in 1984, though total fuel consumption in transportation sector continued to increase (Holcomb et all, 1987). Similar gain due to the fuel efficiency of vehicles continued steadily in further years also. In 1990, total distance travelled by vehicles was much higher than in 1983, however, due to the average fuel efficiency of vehicle stock, fuel consumption by transportation sector increased very slowly (Report DOE/EIA-0464(91), 1993).

Unlike in the transportation sector, energy efficiency improvements revealed considerable effects in developed countries even before 1980 in the industrial sector. For instance, compared to 1972 energy consumption and output level, energy consumption in largest ten industries of US declined by 2.5% while their output increased by 17% in 1979. Weighted average energy efficiency in targeted industries increased by 15.4% between 1972 and 1979 (Report DOE/CE-0015, 1980). According to the same report, there was a potential to increase energy efficiency by 20%-30% depending on the nature of each industrial sub-sectors. Since projections of the report showed that by 1990 output of the Industrial Sector expected to be around 50% higher than 1979 level, energy efficiency improvement programs had to be further strengthened. There were supporting studies showing that energy efficiency would increase further. For instance, Report DOE/PE-0029/2 (1983) showed that between 1974 and 1982 total energy consumption of US per dollar of economic output declined by 18% and projections showed that economic output would increase higher than energy consumption. Same report showed that in 1960's energy consumption per dollar of economic output declined 2% per year, in 1970s 4% per year and further decline is expected to be again 2% per year. Decline in energy consumption per dollar of economic output in industrial sector were observed in Western European countries also. (Trends in Energy Use in Industrial Societies, 1980). Compared to US, energy consumption per dollar of economic output in Western European countries was even lower. In US, energy consumption in large proportion of industrial sector constituted only small proportion of production costs. Around 86% of industrial output was produced with energy costs of 5% and below of total production costs. Major industrial energy use was in petroleum refining, industrial gases production, glass and cement manufacturing, primary metal production and paper industries that in total consumed more than 75% of industrial energy use (Industrial Energy Efficiency, OTA-E-560, 1993).

Energy consumption in residential and services sectors reveal patterns similar to the industrial and transportation sectors. In the residential sector, between 1970 and 1982 number of households increased annually by 2.5% while energy consumption per household decreased by 2.5% due to the energy efficiency (Report DOE/PE-0029/2, 1983). According to the same report, energy efficiency of equipment used in residential sector reached to 70% level and similar equipment used for services sectors already attained 74 level%. Therefore, their projections for residential sector till 2010 revealed that the number of households would increase by 40% and energy consumption per household would decrease by 25%. Another report attributed less importance to the energy consumed by the equipment used in residential and services sectors and concentrated mainly in the energy used for heating in both sectors. That report revealed that due to the progresses in insulating of new houses and efficient heating systems, energy consumed for heating of buildings would be decreased by 33% between 1970 and 2000. There was already a decreasing trend in energy consumption per household between 1970 and 1977 and projections of reporters based on entirely heating improvements showed that by the year 2000 energy consumed in buildings would be 22% lower than the 1977 level (Report EMD-81-74, 1981). In fact, energy efficiency improvements in household appliances had a positive and direct effect in energy consumed for heating the buildings. Report of Hirst & Carney (1977) showed that by 1980s almost 35% of the heating in buildings would be by the electrical systems and even 5% efficiency increase in those systems would lead to 50% energy savings in appliance improvement program. According to the report, advanced electrical heap-pump systems required around 40% of energy consumed by resistance type room heaters, there was a potential to decrease energy consumption in buildings heating through energy efficient appliances. Since energy consumed in those years by appliances in Residential and Services sectors constituted 27% and 30% respectively and their total consumption of energy was approximately 9% total energy consumed in US (Report HIT-691, 1977), improvements in appliance energy efficiency was as important as improvements in heating.

CHAPTER 3

DATA AND METHODOLOGY

Datasets for energy consumption and GDP are retrieved from International Energy Agency and World Bank respectively. Original energy consumption dataset contains sectoral level disaggregated data as primary and final energy consumption series for almost all countries. However, for many countries, especially for less developed ones, data has missing values. In order to conduct proper analysis with sufficient series, most of the developing countries are eliminated from the dataset. There are also developed countries with missing or short period data. Similar to energy consumption dataset, GDP data also has missing values for some countries. Thus, this study is conducted with data that is available in both dataset at sufficient length. There are thirty-two selected countries. For majority of them, sector-wise TFEC and GDP data are available for a period of 1971-2019. Data for some countries is available only for a period of 1990-2019.

3.1 Aggregate and Disaggregated GDP Data Per Capita

GDP data of countries are downloaded from the World Bank together with the population data. Countries selected are those for which energy consumption data is present for longer period. In order to create per capita GDP (GDPPC) data, GDP series of countries are divided by the corresponding population series. GDP percentage share series of industrial sector and services sector are obtained from the World Bank database and GDPPC series are multiplied by the percentage share series in order to create sector-wise GDPPC data. Other sectors GDP per capita (OGDPPC) is created through deducting industrial sector GDP per capita (IGDPPC) and services sector GDP per capita (SGDPPC) values from the GDPPC series. Only for few countries, sector-wise GDPPC is present for entire 1971-2019 period. For the majority of countries, series period is available for 1990-2019 period. Therefore, major dataset for all countries for sector-wise analysis is constructed starting from 1990. However, in order to have clearer picture about the entire period, initial dataset with full series is used as a supporting dataset for sector-wise analysis. For cointegration tests between aggregate GDP and TFEC, original series and their per capita series are used for full available period and for shortened 1990-2019 period (see Appendix A for ADF test results on GDP; Appendix B for ADF test results on Energy Consumption).

GDP and GDPPC can be formulated from aggregate output function as follows :

$$Y = A * K^a * L^b \tag{3.1}$$

where $a + b$ =1, A is the level of technology, K is Capital and L is Labor.

Since GDP is a sum of all products and services valued at their prices, multiplying both sides of Equation (3.1) with the price level turns the equation to GDP. For simplicity, when price level is taken as 1, $GDP = Y = A * K^a * L^b$.

Taking $L = \alpha * P$ for employed proportion of population where P is population, both sides of Equation (3.1) divided by P

$$\frac{Y}{P} = \alpha * A * K^a * L^{b-1}. \tag{3.2}$$

Since $b - 1$ = - a we can rewrite Equation (3.2) as

$$\frac{Y}{P} = \alpha * A * (K^a/L^a) \tag{3.3}$$

Respresenting as Y/P = y and K^a/L^a = k^a, Equation (3.3) turns to

$$GDPPC = y = \alpha * A * k^a \qquad (3..4)$$

For sector-wise disaggregated GDPPC it is necessary to disaggregate both sides of production function. Using the percentage share data of Industrial and Services Sectors obtained from World Bank, GDPPC can be disaggregated as follows

$$GDPPC = y = ind * y + ser * y + (1 - ind - ser) * y = IGDPPC + SGDPPC + OGDPPC \quad (3.5)$$

Through constructing a production function for each sector individually and setting the price level as one in each sector, GDP can be represented as follows:

$L = L_i + L_s + L_o$ where $L_i = i * L$, $L_s = s * L$, $L_o = o * L$ and $i + s + o = 1$. Shares of labor in each sector is represented by i, s and o. Since $L = \alpha * P$, labor in each sector can be represented as $L_i = \alpha * i * P$, $L_s = \alpha * s * P$ and $L_o = \alpha * o * P$.

Similarly, capital share of each sector can be represented as $K_t = K_i + K_s + K_o$ where K_t is total capital, K_i, K_s and K_o represent capital level of industrial, services and other sectors respectively. Then sector-wise disaggregated production function becomes

$$GDP = Y = A_i * K_i^{a} * L_i^{b} + A_s * K_s^{c} * L_s^{d} + A_o * K_o^{e} * L_o^{f} \quad (3.6)$$

where $a + b = 1,\ c + d = 1, e + f = 1$ A_i, A_s and A_o are technology levels unique for each sector.

Dividing both sides by P, sector-wise production function turns to

$$GDPPC = \frac{Y}{P} = A_i * K_i^{a} * L_i^{b}/P + A_s * K_s^{c} * L_s^{d}/P + A_o * K_o^{e} * L_o^{f}/P \ . \quad (3.7)$$

Since $P = L_i/\alpha * i = L_s/\alpha * s = L_o/\alpha * o$,

$$GDPPC = \frac{Y}{P} = \alpha * i * A_i * K_i^{a} * L_i^{b-1} + \alpha * s * A_s * K_s^{c} * L_s^{d-1} + \alpha * o * A_o * K_o^{e} * L_o^{f-1} \quad (3.8)$$

For $b - 1 = -a$, $d - 1 = -c$ and $f - 1 = -e$

$$GDPPC = \frac{Y}{P} = \alpha * i * A_i * \frac{K_i^{a}}{L_i^{a}} + \alpha * s * A_s * \frac{K_s^{c}}{L_s^{c}} + \alpha * o * A_o * K_o^{e}/L_o^{e} \quad (3.9)$$

Representing $k_i = K_i/L_i$, $k_s = K_s/L_s$ and $k_o = K_o/L_o$

$$GDPPC = \frac{Y}{P} = \alpha * i * A_i * k_i{}^a + \alpha * s * A_s * k_s{}^c + \alpha * o * A_o * k_o{}^e \qquad (3.10)$$

Combining two disaggregated formulas thefollowing equations are obtained:

$$IGDPPC = \alpha * i * A_i * k_i{}^a \qquad (3.11)$$

$$SGDPPC = \alpha * s * A_s * k_s{}^c \qquad (3.12)$$

$$OGDPPC = \alpha * o * A_o * k_o{}^e \qquad (3.13)$$

Disaggregation of GDPPC into IGDPPC, SGDPPC and OGDPPC enable to conduct cointegrating analysis with corresponding energy consumption data. In the energy consumption dataset there are ICPC, SCPC and OCPC variables that represent energy consumption series for industrial, services and other sectors, respectively. Unfortunately, data for sector-wise share of GDP is available only for post 1990 period of many countries.

3.2 Cointegration Testing Methods and Causality

In this study, three Cointegration testing methods are utilized in order to countercheck if the results provided by the main method are confirmed by the other two methods. Cointegration testing method developed by Johansen (1988) and by Phillips and Ouliaris (1990) are usually used for testing presence of multiple cointegration between the series. However, first testing method developed by Eangle and Granger (1987) is suitable for testing the presence of cointegration between two series. Therefore, the latter one is selected as the main method of the study. It is a step method, where data is initially tested for stationarity at the original form and at integrating orders. Then, regression model is constructed between the original non-stationary series and the residuals of the model are tested for stationarity. If the model fits well and residuals are stationary, we can conclude that there is a cointegrating relationship between the series. Similar to the main method, testing method of Phillips and Ouliaris (1990) also utilizes residuals for detecting the presence of cointegration. Therefore, it is selected as a main controlling method. Johansen's method is a likelihood ratio test based on vector auto regressions. It is very useful in finding cointegrating relations between several series through a single test. However, Johansen test requires longer series for precise results. Since disaggregated for a period of 1971-2019 is available only for few countries, Johansen's test is not suitable for this study.

The method employed in this study is the Augmented Dickey–Fuller (ADF) t-ratio test, which is particularly practical for detecting a cointegrating relationship between two variables. Stationarity in both levels and first differences is checked with the ADF test. If both variables are non-stationary in levels but stationary in first differences, a regression is run using the original-level variables. Residuals obtained from the model are also tested for stationarity. If the residuals are non-stationary, we conclude that there is no common stochastic trend between the two variables and that the relationship is spurious. Conversely, if the null of non-stationarity is rejected, this indicates cointegration (detailed first-difference test results are presented in Appendix C for GDP and Appendix D for Energy Consumption).

Suppose y_t and x_t are series as:

$$y_t = \alpha_0 + \alpha_1 * y_{t-1} + u_t \tag{3.14}$$

where u_t is an iid error term, y_t and y_{t-1} are Integrated of order one I(1) and y_t- $y_{t-1}$is Integrated of order zero I(0)

$$x_t = \delta_0 + \delta_1 * x_{t-1} + v_t \tag{3.15}$$

where v_t is an iid error term, x_t and x_{t-1} are I(1) and x_t- x_{t-1} is I(0)

The regression model is therefore specified as:

$$y_t = \beta_0 + \beta_1 * x_t + \varepsilon_t \tag{3.16}$$

where ε_t is an iid. error term and we check whether ε_t is I(0) through the ADF regression

$$\Delta\varepsilon_t = \rho * \varepsilon_{t-1} + \sum_{i=1}^{p} b_i * \Delta\varepsilon_{t-i} + \xi_t \tag{3.17}$$

The null hypothesis is $\rho = 0$. Stationarity of ε_t implies the presence of a cointegrating

Because y_t and x_t are I(1), if the obtained ε_t is I(0), then y_t and x_t are cointegrated with the cointegrating coefficient of β_1 given in Equation (3.16).

Once cointegration has been detected, we examine the direction of causality between the variables. The commonly used approach estimates a regression in which lags of the variables are included. Lag orders can be selected through a general-to-specific approach or by information criteria. Suppose the general and specific models are defined as follows:

$$y_t = \alpha_0 + \alpha_1 * y_{t-1} + \alpha_2 * y_{t-2} + \alpha_3 * y_{t-3} + \alpha_4 * x_{t-1} + \alpha_5 * x_{t-2} + \alpha_6 * x_{t-3} + u_t \tag{3.18}$$

$$y_t = \beta_0 + \beta_1 * y_{t-1} + \beta_2 * y_{t-2} + \beta_3 * y_{t-3} + v_t \tag{3.19}$$

If the model in Equation (3.18) has more explanatory power than Equation (3.19), this indicates causality running from x_t to y_t. Similarly, we test the reverse direction with

$$x_t = \alpha_0 + \alpha_1 * x_{t-1} + \alpha_2 * x_{t-2} + \alpha_3 * x_{t-3} + \alpha_4 * y_{t-1} + \alpha_5 * y_{t-2} + \alpha_6 * y_{t-3} + u_t \tag{3.20}$$

$$x_t = \beta_0 + \beta_1 * x_{t-1} + \beta_2 * x_{t-2} + \beta_3 * x_{t-3} + v_t \tag{3.21}$$

Based on the causal direction, error-correction models (ECMs) are constructed:

$$y_t = \beta_0 + \beta_1 * x_t + u_t \tag{3.22}$$

$$\Delta y_t = \alpha * \hat{u}_t + \delta_1 * \Delta x_t + \delta_2 * \Delta x_{t-1} + \varphi_1 * \Delta y_{t-1} + \varepsilon_t \tag{3.23}$$

The main aim is to obtain a stationary residual term, u_t.

CHAPTER 4

FINDINGS AND INTERPRETATION

Cointegration studies begin with stationarity tests of the variables used in the research. As the first step, the level and first differences of Population, GDP, TFEC, GDPPC and TFECPC for each country are tabulated. Joint inspection of Table 4.1 and Table 4.2 clearly indicates that, if cointegration analysis were conducted between GDP and TFEC, the number of countries studied would be much smaller than in the cointegration analysis between GDPPC and TFECPC. Despite that, analysis was conducted for both alternatives (see Appendix A–D for complete country-level ADF p-values).

4.1 Cointegration Analysis Result between GDP and TFEC

Initial condition to conduct an analysis is being sure that level variables are integrated of order one and first differences of them are integrated of order zero.

Table 4.1 p-values of the ADF Test for Level Variables

Country	*Population*	*GDP*	*TFEC in PJ*	*GDPPC*	*TFECPC in GJ*
Australia	0.9900	0.6742	0.9314	0.4964	0.9900
Austria	0.6590	0.4754	0.6790	0.8988	0.8913
Belgium	0.7584	0.4132	0.6589	0.6408	0.8210
Brazil	0.8825	0.3285	0.4478	0.3595	0.4242
Chile	**0.0100**	0.3786	0.3691	0.2365	0.5914
China	0.4655	0.6596	0.3451	0.5839	0.3328

Colombia	0.1025	0.9641	0.1687	0.7773	0.2384
Denmark	0.7979	0.3460	0.0685	0.5851	0.0782
France	0.1372	0.4333	0.9716	0.7307	0.9537
Finland	0.3969	0.3543	0.9447	0.3771	0.9307
Germany	0.3076	0.5209	0.0297	0.2825	0.0383
Greece	0.9900	0.1613	0.9370	0.0811	0.9138
Hungary	0.1989	0.1431	0.4569	0.1520	0.4370
India	**0.0100**	0.9900	0.7240	0.9900	0.6692
Indonesia	**0.0100**	0.9851	0.5940	0.9535	0.6899
Italy	0.0647	0.9610	0.9201	0.9223	0.8676
Japan	0.5459	0.9224	0.9900	0.8525	0.9774
Korea	0.8818	0.0888	0.6165	0.1236	0.7874
Mexico	0.3703	0.5081	0.6317	0.1022	0.3094
Morocco	**0.0100**	0.7245	0.5445	0.7733	0.6898
Netherlands	0.4872	0.3694	0.5791	0.4373	0.4242
New Zealand	0.9094	0.7856	0.7408	0.4805	0.9074
Norway	0.7481	0.6122	0.5629	0.9725	0.7636
Poland	0.2392	0.9878	0.5069	0.9900	0.5297
Portugal	**0.0100**	0.4210	0.7131	0.4060	0.7410
South Africa	**0.0100**	0.8485	0.6150	0.9350	0.6681
Spain	0.0970	0.0870	0.3370	0.2900	0.4650
Sweden	0.9850	0.8900	0.4230	0.4660	0.5710
Switzerland	0.8870	0.9470	0.9630	0.3530	0.9210
Thailand	**0.0100**	0.6250	0.0260	0.5490	0.0110
Türkiye	**0.0100**	0.9900	0.9900	0.9600	0.5760
United Kingdom	0.4060	0.3050	0.8430	0.5310	0.9200
United States	0.9040	0.5230	0.4180	0.4030	0.3240

p<0.05 was considered statistically significant

Table 4.2 p-values of the ADF Test of First Differences of Variables (Variable_D)

Country	*Population _D*	*GDP_D*	*TFEC_D in PJ*	*GDPPC_D*	*TFECPC_ D in GJ*
Australia	0.9762	0.5244	0.0036	0.0483	0.0000
Austria	0.0237	0.0186	0.0000	0.0057	0.0000
Belgium	0.4950	0.0447	0.0000	0.0153	0.0000
Brazil	0.2790	0.0796	0.0946	0.0202	0.0298
Chile	0.2720	0.0939	0.0139	0.0136	0.0026
China	0.1226	0.1890	0.2410	0.2820	0.1890
Colombia	0.4750	0.2370	0.0019	0.0273	0.0000
Denmark	0.0714	0.0155	0.0000	0.0049	0.0000
France	0.2160	0.0320	0.0000	0.0076	0.0000
Finland	0.1380	0.0009	0.0000	0.0005	0.0000
Germany	0.0098	0.0015	0.0000	0.0003	0.0000
Greece	0.1072	0.0063	0.0011	0.0025	0.0003
Hungary	0.4370	0.3190	0.0017	0.3770	0.0026
India	0.6690	0.9550	0.7440	0.7460	0.4400
Indonesia	0.5280	0.4760	0.0245	0.1350	0.0033
Italy	0.0369	0.0025	0.0004	0.0022	0.0005
Japan	0.0003	0.0101	0.0000	0.0050	0.0000
Korea	0.1210	0.2160	0.0196	0.1320	0.0100
Mexico	0.2300	0.0095	0.0102	0.0002	0.0026
Morocco	0.5300	0.6030	0.1240	0.2060	0.0232
Netherlands	0.5143	0.0313	0.0000	0.0068	0.0000
New Zealand	0.3120	0.2350	0.0178	0.0161	0.0022
Norway	0.6000	0.0969	0.0000	0.0355	0.0000
Poland	0.0041	0.8070	0.0039	0.8020	0.0031
Portugal	0.0056	0.0078	0.0296	0.0015	0.0212

South Africa	0.1090	0.1740	0.0014	0.0114	0.0003
Spain	0.0740	0.0300	0.0061	0.0095	0.0034
Sweden	0.5930	0.0076	0.0000	0.0010	0.0000
Switzerland	0.5120	0.0805	0.0000	0.0039	0.0000
Thailand	0.5350	0.1500	0.0886	0.0810	0.0497
Türkiye	0.0908	0.0484	0.0025	0.0057	0.0000
United Kingdom	0.7670	0.0192	0.0000	0.0051	0.0000
United States	0.5970	0.1150	0.0000	0.0120	0.0000

$p<0.05$ was considered statistically significant

1. First differences for Australia, Brazil, Chile, China, Colombia, Hungary, India, Indonesia, Korea, Morocco, New Zealand, Thailand, South Africa and United States are not stationary.

2. There is no cointegration between variables for Belgium, Denmark, Finland, France, Greece, Italy, Japan, Mexico, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Türkiye or United Kingdom.

3. Cointegration is present for Austria and Germany.

These results highlight that the commonly used aggregate-level analysis does not provide the desired information on the GDP–energy-consumption relationship across countries. Moreover, observed cointegration between Population and GDP in Germany, and between Population and TFEC in Japan and Germany, motivated the use of per-capita variables to eliminate the population effect.

4.2 Cointegration Analysis Result between GDPPC and TFECPC

1. First differences of variables for China, Hungary, India, Indonesia, Korea, Morocco and Poland are not stationary.

2. There is no cointegration between variables of Australia, Belgium, Chile, Colombia, France, Finland, Greece, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Portugal, Spain, Türkiye, South Africa and United Kingdom.

3. There is a cointegration between variables of Austria, Brazil, Denmark, Germany, Sweden, Switzerland, Thailand and United States.

Table 4.1 Cointegration Test Result Between per Capita Variables

Country	*Coefficient*	*Coefficient p-Value*	*Adj R^2*	*Residual Unit Root test*
Australia	813.34	0.0000	0.5826	0.4010
Austria	484.55	0.0000	0.9351	0.0305
Belgium	348.23	0.0000	0.4675	0.5180
Brazil	187.38	0.0000	0.9717	0.0148
Chile	229.19	0.0000	0.9138	0.5060
Colombia	368.57	0.0001	0.2744	0.5320
Denmark	-638.80	0.0000	0.3308	0.0410
France	-113.60	0.4981	-0.0113	Not conducted
Finland	490.60	0.0000	0.7762	0.1400
Germany	-732.80	0.0000	0.4908	0.0027
Greece	213.16	0.0000	0.8675	0.1100
Italy	495.56	0.0000	0.7875	0.6160
Japan	501.89	0.0000	0.5769	0.9160
Mexico	190.37	0.0000	0.4238	0.8041
Netherlands	146.00	0.0000	0.0103	Not conducted
New Zealand	246.60	0.0000	0.4363	0.9570
Norway	789.70	0.0000	0.4975	0.6410
Portugal	206.24	0.0000	0.9075	0.2190
South Africa	-39.34	0.4397	-0.0135	Not conducted

Spain	281.92	0.0000	0.8231	0.5390
Sweden	-564.41	0.0000	0.6471	0.0268
Switzerland	-691.80	0.0000	0.3573	0.0378
Thailand	90.62	0.0000	0.9670	0.0758
Türkiye	253.09	0.0000	0.9560	0.1230
United Kingdom	-514.50	0.0002	0.2400	0.1520
United States	-487.70	0.0000	0.6720	0.0208

$p<0.05$ was considered statistically significant

Table 4.3 highlighted very important feature of the cointegration relationship between variables across countries. Negative signs observed for coefficients of Denmark, Germany, Sweden, Switzerland and United States while for other countries coefficient signs are positive. The reason of difference might be a development level of studied countries or the maturity level of industries in them. The result is also not in line with the studies of Soytaş & Sarı (2003) who found cointegrating relations and causal effect between variables of France, Italy and Türkiye through employing GDP per capita and aggregate level Energy Consumption variables. Difference in the results might be sourced from the fact that in this analysis both variables are at per Capita, while in their studies only one variable is used at per Capita level. Moreover, they used natural logs of variables where in this study variables are in their natural from.

4.3 Visual Exploratory Analysis of Disaggregated GDPPC and Disaggregated TFECPC data

As a second step, both GDPPC and TFECPC are disaggregated by sectors in order to conduct proper analysis. GDPPC disaggregated into Industrial Sector GDP per Capita (IGDPPC), Services Sector GDP per Capita (SGDPPC) and Other Sectors GDP per Capita (OGDPPC) while TFECPC grouped as Industrial Sector Energy

Consumption per Capita (ICPC), Services Sector Energy Consumption per Capita (SCPC), Other sectors Energy Consumption per Capita (OCPC), Residential Energy Consumption per Capita (RCPC) and Transports Energy Consumption per Capita (TCPC). Three sector Energy Consumptions directly related with the three production sectors of the GDP. However, RCPC and TCPC mainly related with the private consumption and investment behavior of households. Therefore, they either have to be tested with aggregate GDPPC or with one of the sectoral GDPPC series. Perhaps the best candidate is the IGDPPC since energy consumed in residential and transports sectors are in fact final products of industrial sector.

Before conducting cointegration test, preliminary visual exploratory analysis is applied to the disaggregated data of countries. Figures indicate that Sector wise Energy Consumptions are declining in developed countries while increasing in developing countries. For instance, Figure 4.1 demonstrates that all sectoral energy consumption per capita variables are increasing in China while they are declining in United Kingdom (Figure 4.2).

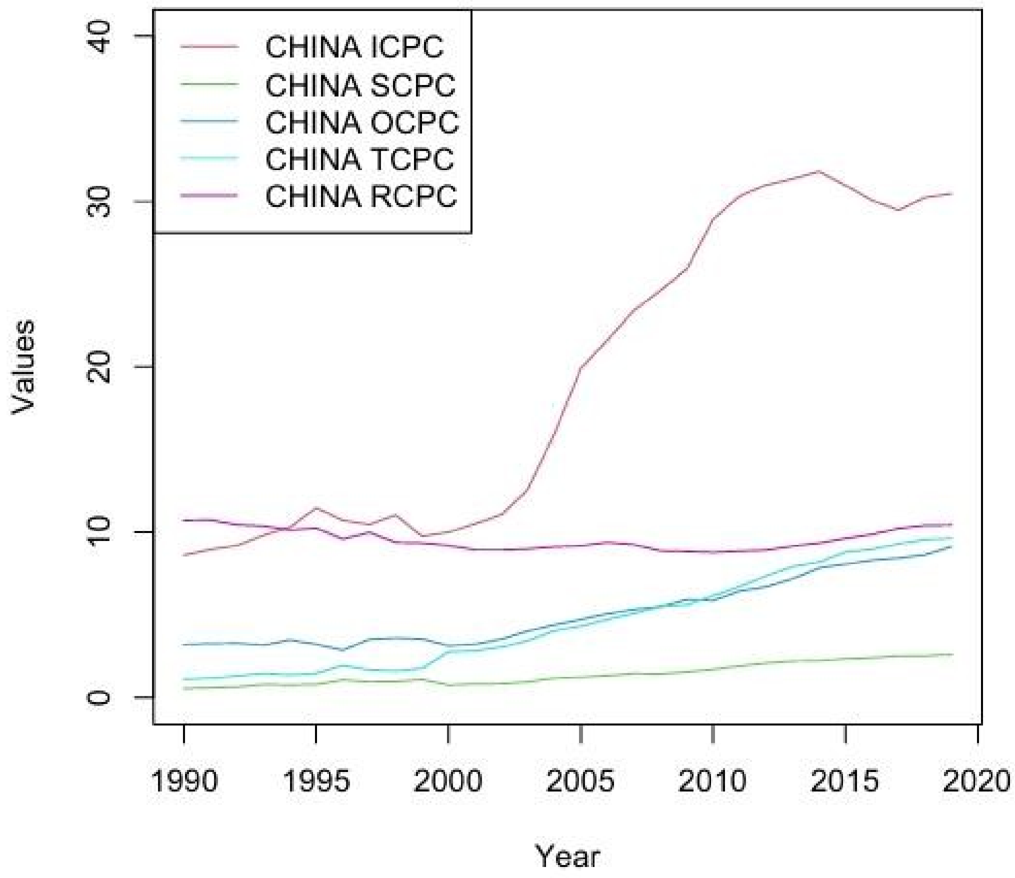

Figure 4.1 China Sector-wise Disaggregated per Capita Energy Consumption

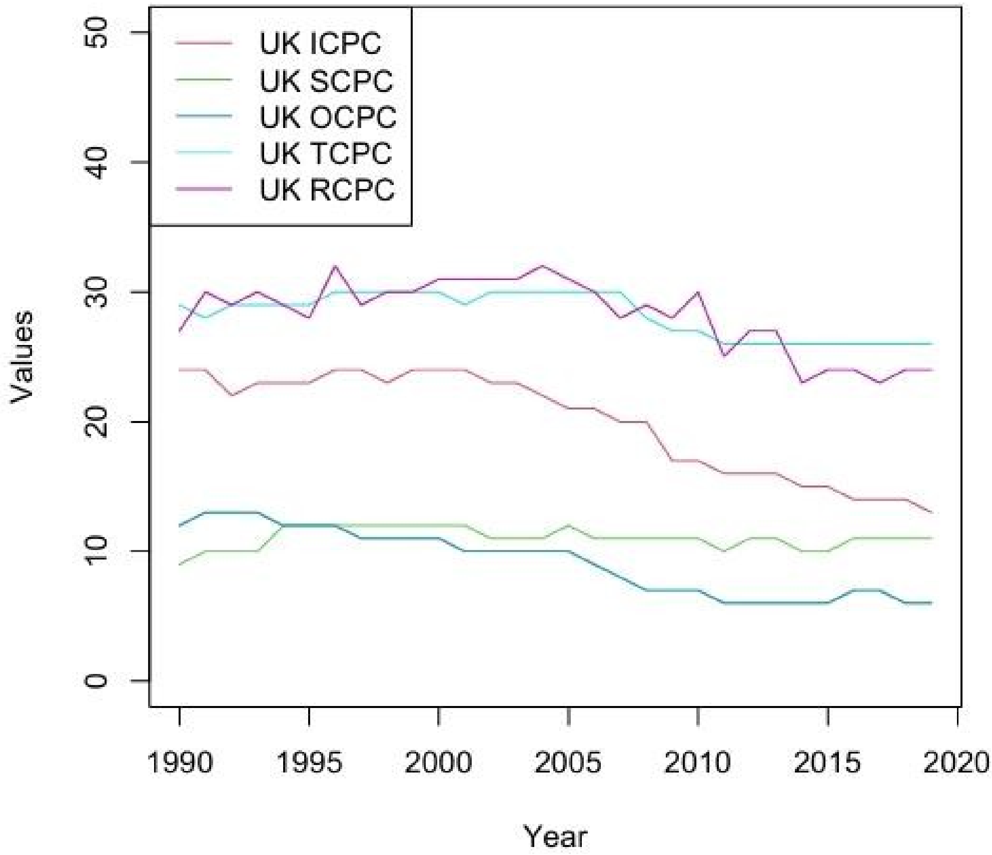

Figure 4.2 UK Sector-Wise Disaggregated per Capita Energy Consumption

Besides Energy Consumption pattern differences, there is also a difference in sectoral GDPPC patterns between developed and developing countries. In developed countries IGDPPC demonstrate almost flat pattern while in developing countries it is upward sloping. See Figures 4.3 and 4.4 as an example.

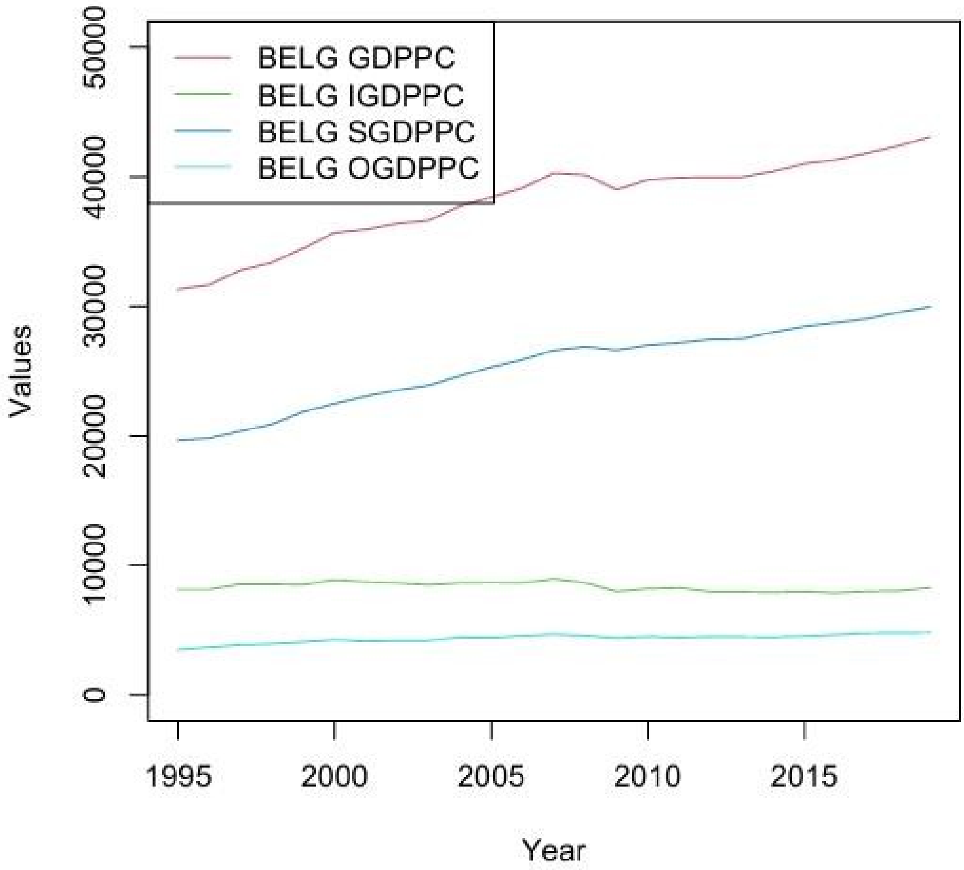

Figure 4.3 Belgium Aggregate & Disaggregated GDP per Capita

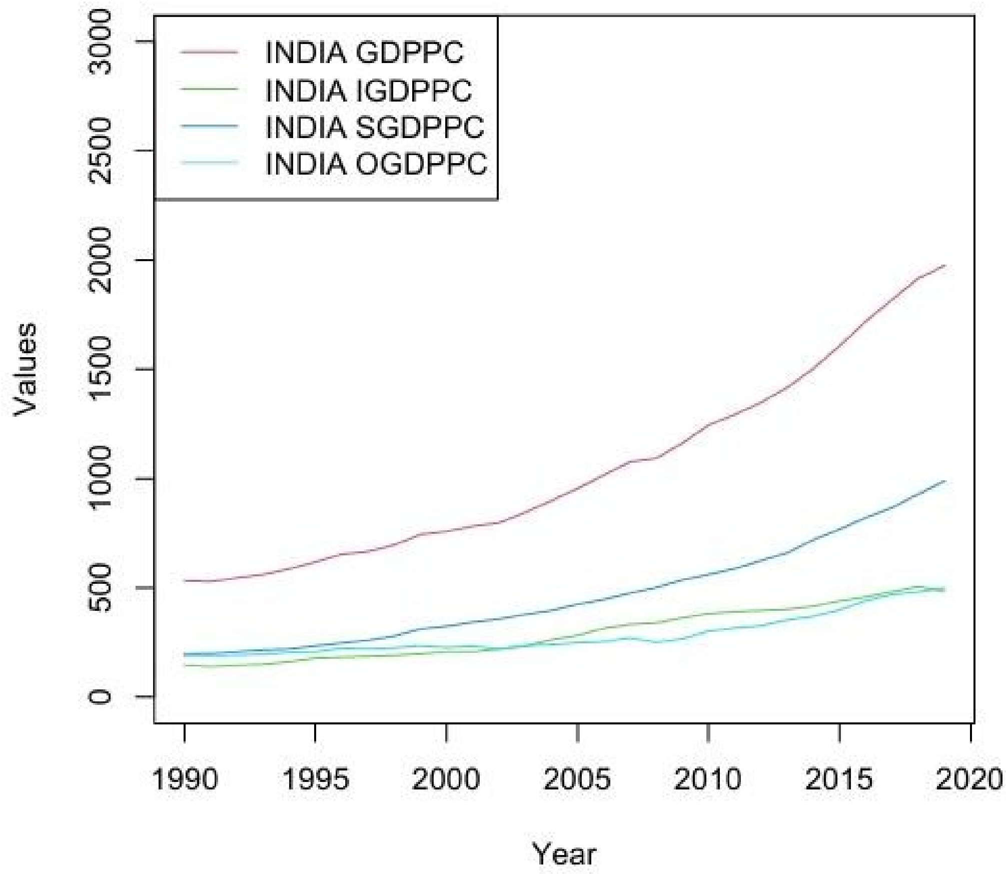

Figure 4.4 India Aggregate & Disaggregated GDP per Capita

Disaggregation of GDP by industries enables to observe unique features of each industry in the analyzed country. Plotting GDPPC together with IGDPPC, SGDPPC and OGDPPC values in a single diagram provides an opportunity to analyze the movement behavior of series for each sector throughout the period.

Visual analysis of plots demonstrated that for the studied period in developed countries GDPPC and SGDPC reveals similar pattern. In the same countries, IGDPPC and OGDPC revealed very different pattern than GDPPC and SGDPPC. Such patterns shed a light to the plausible results observed during the cointegration tests with aggregate GDPPC. Figure 4.3 shows that in developed countries IGDPPC and OGDPPC almost stayed at the same level throughout the studied period. However, SGDPPC continuously increased and leaded GDPPC to follow the similar pattern. On the other hand, in developing countries IGDPPC and OGDPPC followed increasing pattern throughout the studies period though trend was lower than that of in the SGDPPC.

Difference in patterns observed between IGDPPC of developed and developing countries well explained in the economic theory. According to the theory, GDPPC and Capital per Capita of countries continue to increase until the point where the economy reaches to a steady state level. At the steady state level, per Capita output and capital levels stay at the same level for a long period until there is a technological change that start shifting the production level upwards. However, theory claims that economy reaches to the steady state as a whole. Contrary to the theory, we observe such pattern only in IGDPPC and OGDPC. In the services sector, growth continues while other two sectors are in the steady level (see Appendix E for countries that experience steady state in industrial sector GDP per capita). In fact, this pattern leaded to the plausible result in cointegration tests with the aggregate GDP.

Analysis of sector wise GDPPC and energy consumption per capita Figures also revealed another interesting pattern. Regardless of GDPPC values of the countries, RCPC of neighboring countries reveals similar pattern. For instance, Figure 4.5 demonstrates that Residential Energy Consumption is more sensitive to fluctuations in climatic conditions than in per Capita production levels. Moreover, Table 4.4 supports the pattern observed in Figure 4.5 through the solid examples of relationship between average Europe Temperature and RCPC series of European countries.

Table 4.2 Regression Result of 1st Differences of RCPC and EU Temperature

Country	*Coefficient of Temperature*	*Significance of Temperature(p-value)*	*Adjusted R-Squared*
Austria	-2.12	0.0000	0.3450
Belgium	-2.53	0.0005	0.2176

Denmark	-3.51	0.0000	0.3670
Finland	-2.35	0.0006	0.2110
France	-2.10	0.0000	0.3235
Germany	-2.66	0.0000	0.3917
Hungary	-1.39	0.0163	0.1717
Italy	-1.15	0.0001	0.2561
Netherlands	-3.17	0.0000	0.4587
Norway	-1.87	0.0001	0.2910
Poland	-2.01	0.0000	0.5214
Sweden	-2.90	0.0001	0.2554
Switzerland	-2.16	0.0000	0.4728
UK	-1.63	0.0000	0.3404

$p<0.05$ was considered statistically significant

Table 4.4 shows that there is a negative relationship between RCPC and Annual Average Temperature of Europe. Each Celsius degree increase in Annual Average Temperature of Europe decreases the RCPC by more than 2 GJ in many European countries.

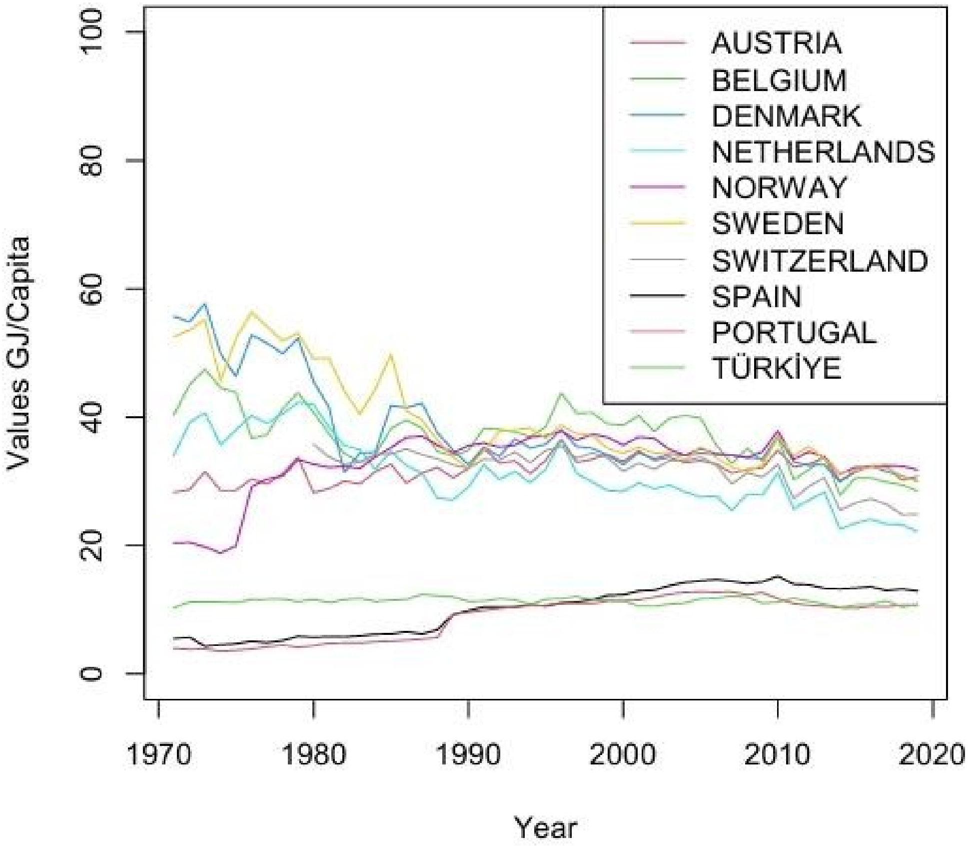

Figure 4.5 Europe RCPC by Country

From top to bottom of the Figure 4.5, countries of Europe clearly show that RCPC levels are higher in the regions close to the North Pole and lower in the regions close to Mediterranean Sea. In the Northern regions of Europe, RCPC of countries fluctuate together and there is a sign of convergence. Beta Converge test confirms that RCPC variables of UK, France, Sweden, Norway, Finland, Denmark, Germany, Belgium, Netherlands and Austria reveal a converging pattern with a Beta Convergence coefficient of -0.0184.

Such pattern in RCPC series of countries directed to investigate for the possibility of similar patterns in other Energy Consumption sectors. Fortunately, similar pattern was present in TCPC of neighboring countries. Figure 4.6 shows that in European countries, they fluctuate together and there is a sign of convergence. Beta

Convergence test confirms that there is a convergence between TCPC of UK, France, Portugal, Denmark, Germany, Netherlands, Belgium, Italy, Austria and Turkey. Coefficient of Beta Conversion is -0.0147.

Unlike in developing countries, in developed European countries and United States where vehicles market is already saturated, TCPC is downward sloping after 2005. Such pattern indicates that, depreciated vehicle stock of developed countries is renewed with more energy efficient models.

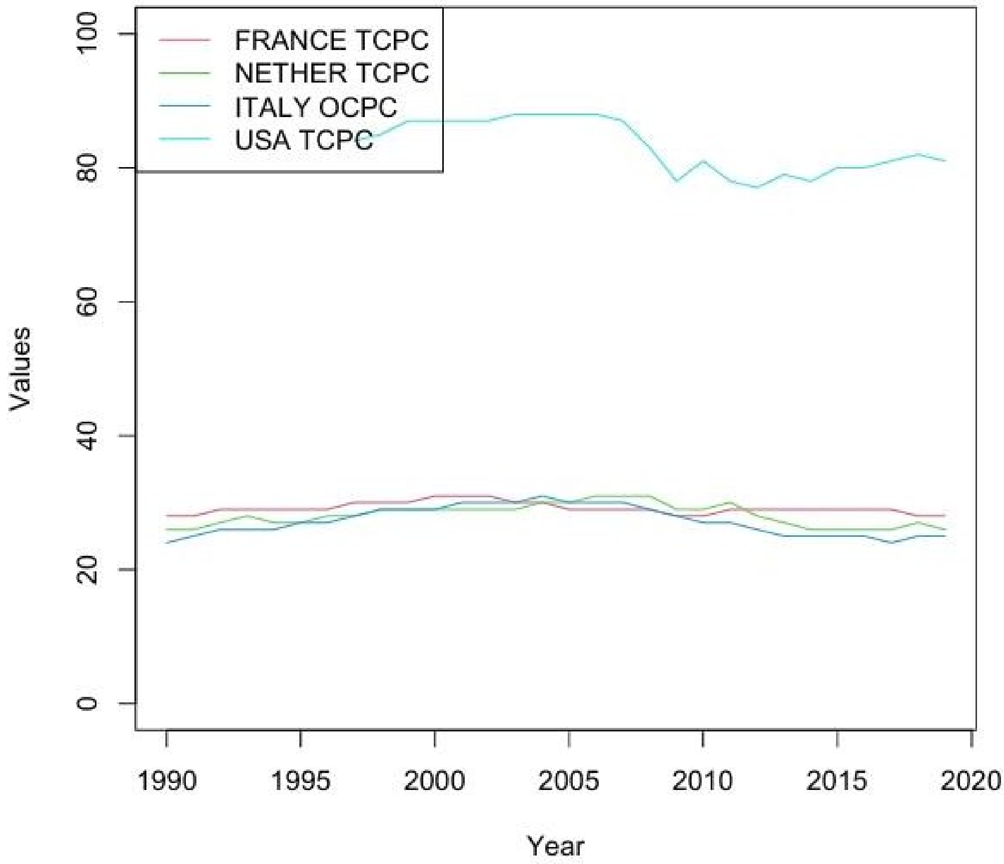

Figure 4.6 TCPC in France, Netherlands, Italy and USA

Despite the fact that vehicle stock of United States also demonstrate similar pattern, Figure 4.6 shows that TCPC of it is far above than the consumption level of European countries. It might be due to the difference in car types preferred by United States and Europe citizens or due to the geographical differences.

Similar to TCPC, there is a geographical pattern in ICPC also. Series of neighboring countries move together and reveal converging pattern.

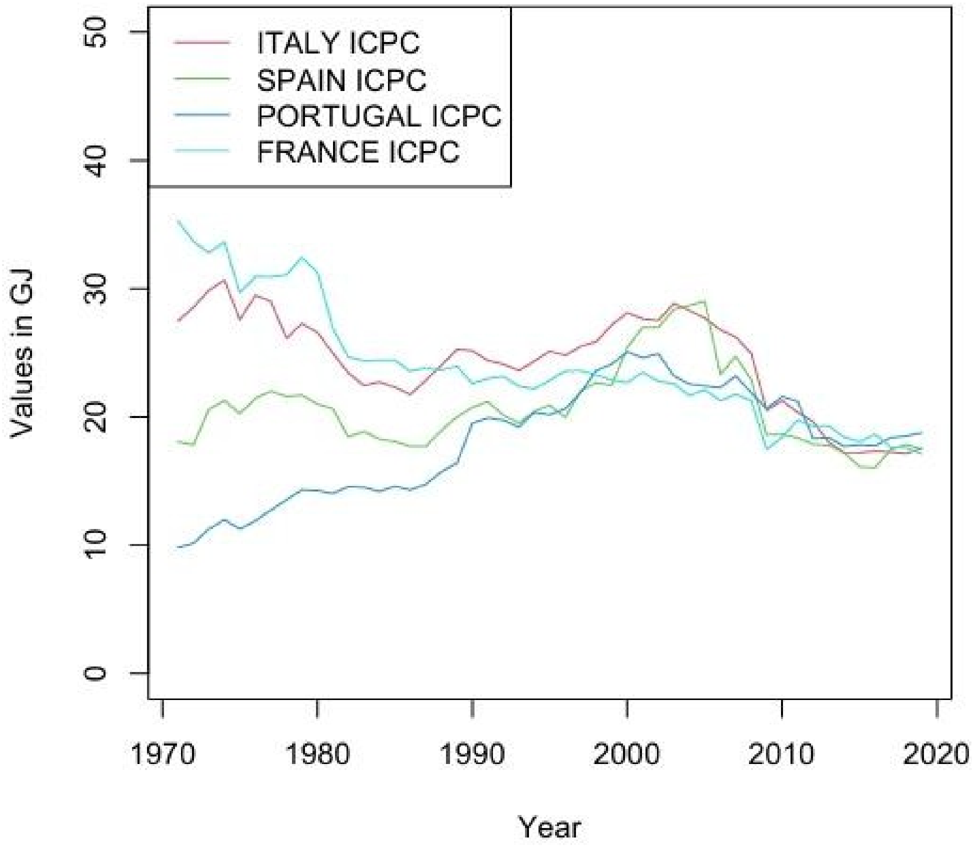

Figure 4.7 ICPC in Italy, Spain, Portugal and France

For instance, Figure 4.7 clearly demonstrates that there is a convergence between ICPC of neighboring countries. Beta convergence test between ICPC of Italy, France, Portugal and Spain resulted with a Beta Convergence coefficient of -0.0222. Such converge indicates that there is a common production pattern in the Industrial Sectors of those economies. However, IGDPPC divided by ICPC demonstrate that countries might be positioned in different levels of common supply chain. Figures 4.8 and 4.9 clearly indicate that.

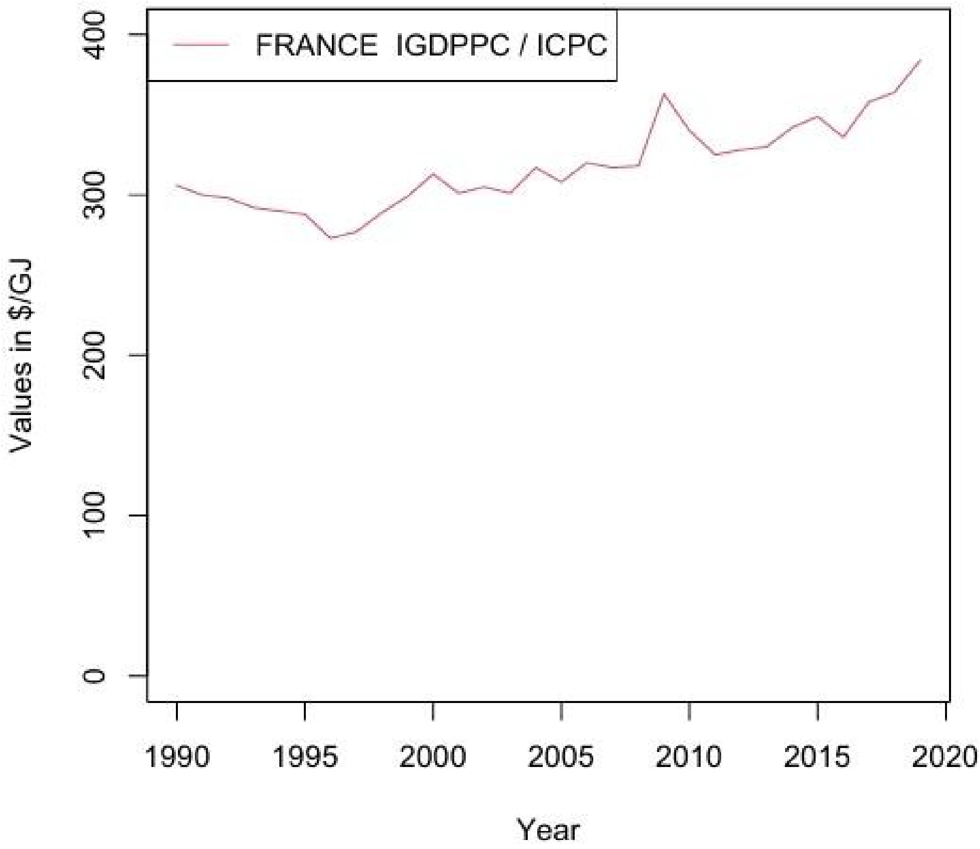

Figure 4.8 France Industrial Sector Contribution to GDP per GJ Energy Consumption

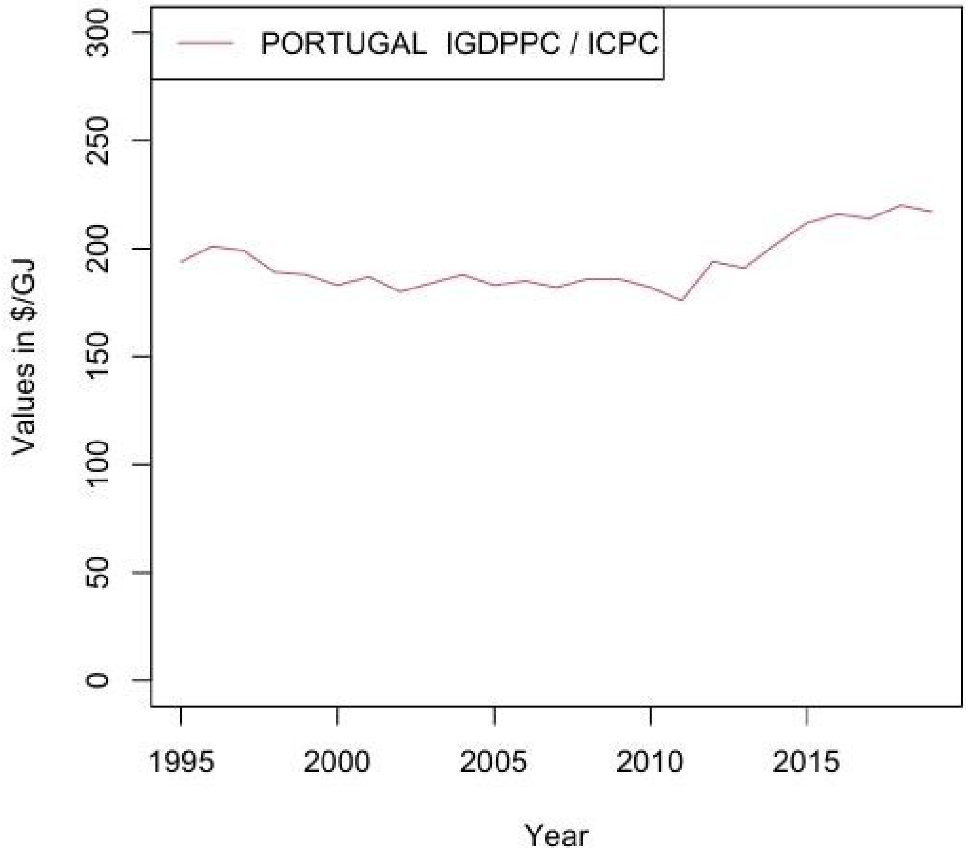

Figure 4.9 Portugal Industrial Sector Contribution to GDP per GJ Energy Consumption

Industrial sector of France contributes to GDP much higher US dollars by using unit GJ Energy compared to Portugal, though they both consume per Capita almost the same level of energy in the industrial sector.

SCPC is also not an exception. Similar pattern is present between neighboring countries (Figure 4.10). Figure 4.10 shows that there is convergence in SCPC between Portugal, Spain, Greece and Türkiye that are competing in the tourism sector. Convergence test confirms that there is a Beta Convergence with a coefficient of -0.0193 between SCPC of Greece, Spain, Portugal and Türkiye.

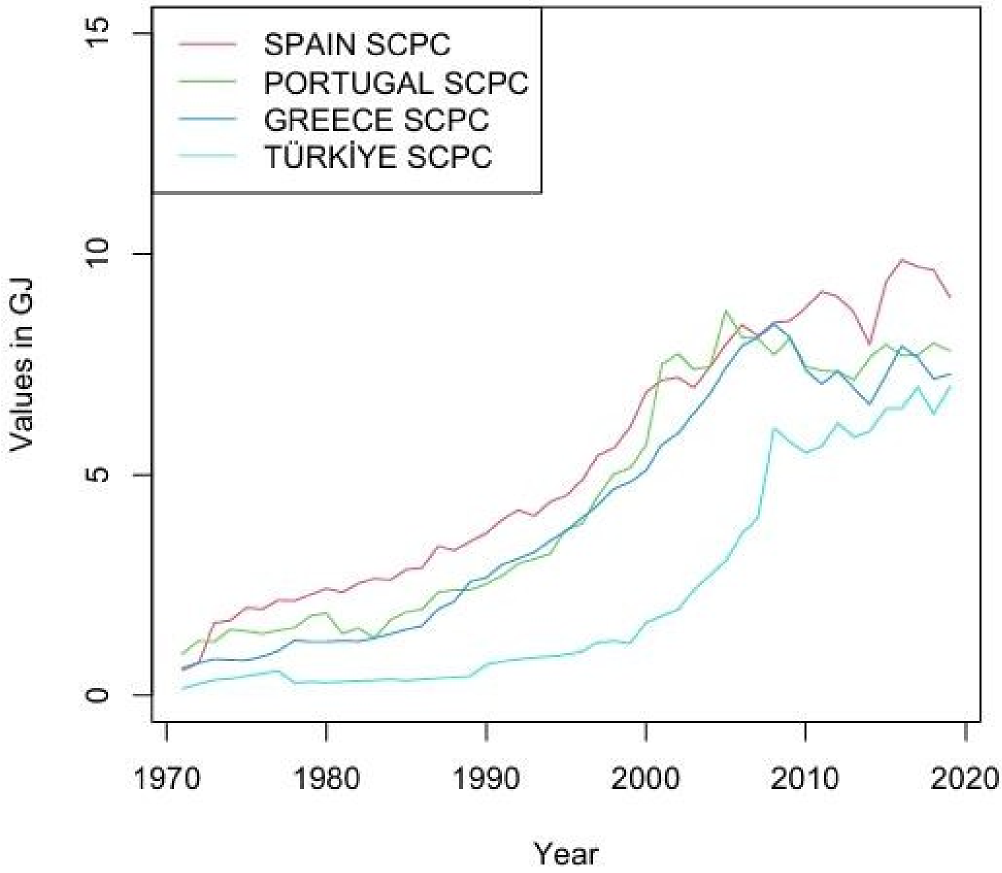

Figure 4.10 SCPC in Mediterranean Countries

All visual exploratory data analysis reveals that cointegration tests should also be conducted between the sector-wise energy consumption per capita variables of neighboring or close related countries in order to see if there is a long-run equilibrium between those series. Therefore, cointegration analysis conducted as follows:

1. Between RCPC of neighboring or alike countries.
2. Between TCPC of neighboring or alike countries.
3. Between ICPC of neighboring or alike countries.
4. Between SCPC of neighboring or alike countries.
5. Between IGDPPC of neighboring or alike countries.

OCPC analysis are not performed since during exploratory data analysis stage it is observed that only few countries have similarity.

4.4 Results of Sectoral Cointegration Analysis Between Neighboring or Alike Countries

Cointegration Analysis Result between RCPC of countries

1. There is a cointegration between RCPC of Denmark & Sweden, Denmark & Belgium, Netherlands & Denmark, Sweden & Finland, Switzerland & Germany, Germany & Austria, Germany & France, France & Spain, Spain & Italy, New Zealand & Australia, Mexico & Brazil, Japan & China, China & India.
2. There is a multiple cointegration between France, Germany and Spain. Adjusted R^2 for France ~ Germany + Spain is 0.8438 while separately Adjusted R^2s are 0.2154 and 0.5687 respectively. Residuals of all models are stationary.
3. There is a cointegration between United States & Norway. The reason might be similarity between the climates of Northern part of United States and Norway.

Cointegration Analysis Result between TCPC of countries

1. There is a cointegration between France & Germany, Denmark & Germany, Denmark & Norway, Denmark & Belgium, Belgium & Netherlands, Denmark & France, Italy & France, Spain & Portugal, Norway & Finland, Denmark & Finland, Australia & New Zealand.
2. There is a cointegration between Japan & United Kingdom, Japan & United States. Though Japan is distant from United Kingdom and United States, Transports Energy Consumption per Capita variables are cointegrated with them.

Cointegration Analysis Result between ICPC of countries

1. There is a cointegration between United Kingdom & Denmark, United Kingdom & France and United Kingdom & Norway in ICPC variables.

Cointegration Analysis Result between SCPC of countries

1. There is a cointegration between Spain & Greece, Portugal & Spain, Portugal & Greece, Türkiye & Greece, Türkiye & Spain.
2. There is a cointegration between France & Italy, Germany & Denmark.

Cointegration Analysis Result between IGDPPC of countries.

1. There is a cointegration between France & Italy, France & Belgium, France & Portugal, Spain & Italy, Portugal & Italy, United Kingdom & United States, United Kingdom & Italy, United Kingdom & France, Sweden & Norway, Finland & Norway, Germany & Türkiye.
2. There is no cointegration between IGDPPC of Türkiye & United States. However, there is a high association between first differences of per Capita Industrial Sector GDP variables of United States & Türkiye. That association might be as important as the information about cointegrating relationship between level variables.

The results of cointegration analysis confirmed the initial insights aroused from visual exploratory data analysis in RCPC, TCPC and SCPC of countries. Although there was no similar performance, cointegrating relationship observed between ICPC of countries. Moreover, in ten pairs of developed countries, there was a cointegrating relationship between IGDPPC.

Cointegration Analysis Result between SCPC and SGDPPC

1. For many countries, SGDPPC was not stationary at first differences. Therefore, cointegration analysis conducted only for few countries. Unfortunately, there is no cointegrating relationship SGDPPC and SCPC of countries except Colombia.

Cointegration Analysis Result between IGDPPC and ICPC

1. There is a cointegrating relationship between the series of Australia, Austria, Belgium, Chile, France, Hungary, Indonesia, Italy, New Zealand, South Africa, Sweden, Switzerland and United Kingdom.
2. Signs of a coefficient in New Zealand, Sweden and Switzerland is negative.
3. Adjusted R^2 of the model for Germany, Japan, Netherlands, Norway and United States is close to zero.

Cointegration Analysis Result between IGDPPC and TCPC

1. There is a cointegration between the variables of Austria, Finland, France, Hungary, Indonesia, Italy, Mexico, Netherlands, New Zealand, Norway, Poland, Türkiye, United Kingdom and United States.

Causality Analysis Result between IGDPPC and ICPC

1. There is a short-run causality between variables of New Zealand, Sweden and Switzerland. The direction of the causality is from IGDPPC to ICPC.

Cointegration tests and causality analysis results between sector-wise Energy Consumption per Capita and sector-wise GDPPC indicate that the relationship between variables might not be linear. Cointegrating relationship observed between variables with positive coefficient in some developing and developed countries, no cointegrating relationship sign observed in some developed countries with almost zero Adjusted R^2 value, and cointegrating relationship observed with a negative coefficient in some developed countries. All these indicate that variables initially converge to each other while countries are developing, and then start to diverge from each other (see Appendix F for country groupings with decreasing TFEC and increasing GDP).

CHAPTER 5

CONCLUSION

Energy is both a factor of production and an essential consumption good in the economy. The purpose of its usage is the most important dimension in setting the policies. This study presents that, cointegration analysis conducted by utilizing disaggregated energy consumption and GDP data reveal much powerful insight about the relationship between two variables. Observed cointegrating relationships between sector-wise disaggregated energy consumption and GDP data indicate that during the development stage of countries, ICPC and IGDPPC move in the same direction. However, when the economy reaches a steady state of the sector, sectoral energy consumption starts declining due to the energy efficiency increase in the accumulated capital. Unlike IGDPPC, SGDPPC continuously increases in both developed and developing countries while SCPC in the sector stops growing and even starts declining. It implies that services sector is not much energy dependent as the industrial sector.

Disaggregation of TFECPC and GDPPC data provided an opportunity to investigate sectoral level data comparisons between countries. Analyses reveal that there are cointegrating relationships between per capita sector-wise energy consumptions of neighboring or integrated countries. Similar relationship observed between sector-wise per capita GDP values of neighboring countries also. Besides an advantage in observing cointegrating relationships, disaggregated data also provide a better insight about the production relationships between sector-wise energy consumption per capita and GDP per capita.

Energy Consumption Mix Differences in Countries

There is a notable difference between per capita Energy Consumption Mix of both developed and developing countries. It is mainly the result of the long-term development strategies and comparative advantages of the countries. Countries can be grouped according to their per capita Energy Consumption Mixes as follows:

1. ICPC > TCPC: Belgium, Chile, China, Finland, Hungary, India, Indonesia, Japan, Korea, Netherlands, Norway, South Africa, Sweden, Thailand, Türkiye.
2. TCPC > ICPC: Australia, Austria, Brazil, Colombia, Denmark, France, Germany, Greece, Italy, Mexico, Morocco, New Zealand, Poland, Portugal, Spain, Switzerland, United Kingdom, United States.

It is natural for developing countries to consume more energy in Industrial Sector during their rapid growth stage. However, in developed countries, high Industrial Energy Consumption mainly sourced from their energy intensive productions like chemical industry.

Observing countries like Brazil, Colombia, Mexico and Morocco in a group of countries where Energy Consumption of Transports Sector is higher than Industrial Sector is leading to question the Energy Policies of those countries. Since Transports Sector is mainly consuming oil products that are usually imported from abroad, most prudential policies are required in that sector.

Policy Implications from the Findings

Contrary to common policy implications derived from cointegration analysis conducted between aggregate GDP and aggregate Energy Consumption variables, policy implications for Türkiye from this study is as follows:

- RCPC in Türkiye will decline in line with the increase of more insulated new type buildings instead of depreciated ones. New policies for replacement of old buildings with more earthquake resistant buildings would also have an impact on reducing Residential Energy Consumption per Capita.

- TCPC in Türkiye will increase in line with increase in GDP per Capita until it converges with the level of European average. However, investment in public transportation lines mainly in railway and airway sectors would have an impact in controlling the speed of the increase.
- SCPC in Türkiye will be similar to those in Spain, Portugal and Greece. Though SGDPPC will increase continuously as in developed countries, Energy Consumption per Capita in the sector will be almost flat in the medium-run and declining in the long run.
- There is an increase in greenhouse farming in Turkish agricultural sector especially in Mediterranean and Aegean regions of Türkiye. Global warming and water scarcity might spread greenhouse framing to other regions also. Sector-wise Energy Consumption of Netherlands demonstrate that there is a necessity for prudential planning and encouraging policies for renewable energy supplied greenhouse constructions. See Figure 5.1.

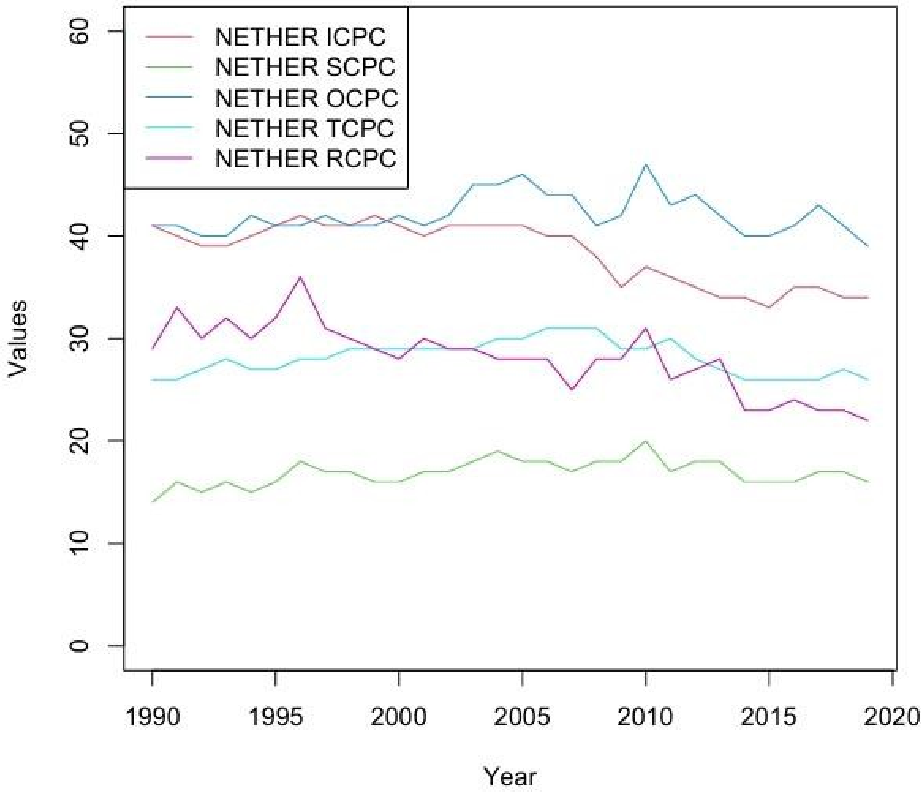

Figure 5.1 Netherlands Sector-Wise Disaggregated per Capita Energy Consumption

- ICPC in Türkiye will converge to those in Germany, Austria, Poland and Hungary. Figure 5.2 shows that there is a convergence between ICPC of Poland, Hungary and Türkiye that are in close production chain with German and Austrian Industries.

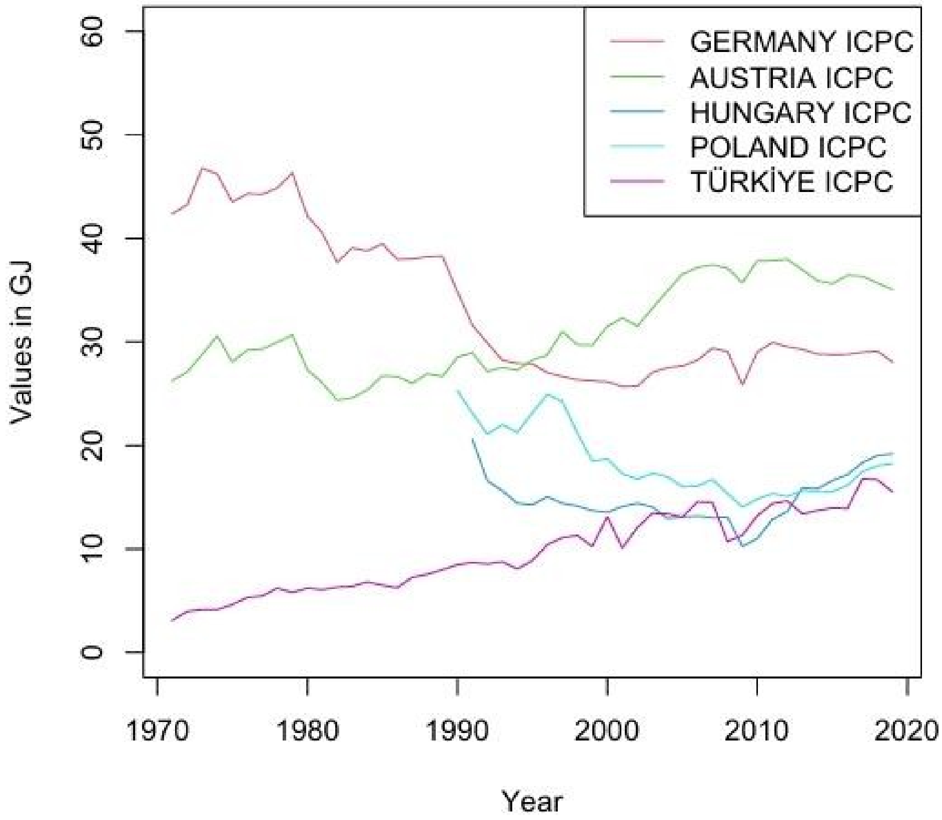

Figure 5.2 ICPC in Germany, Austria, Hungary, Poland and Türkiye

- Depending on new industrial investments, Turkish industry might reveal different pattern in the long run. Currently Industrial sector of Türkiye contributes to GDP per Capita USD by using unit GJ energy at the similar level with Netherlands, Belgium, Poland, Hungary and Portugal. See Figure 5.3. However, it has a potential to increase to the levels of Germany, France, Italy and Japan with the investments in higher technology industrial production. See Figure 5.4 (for supporting statistical evidence see Appendix E–F).

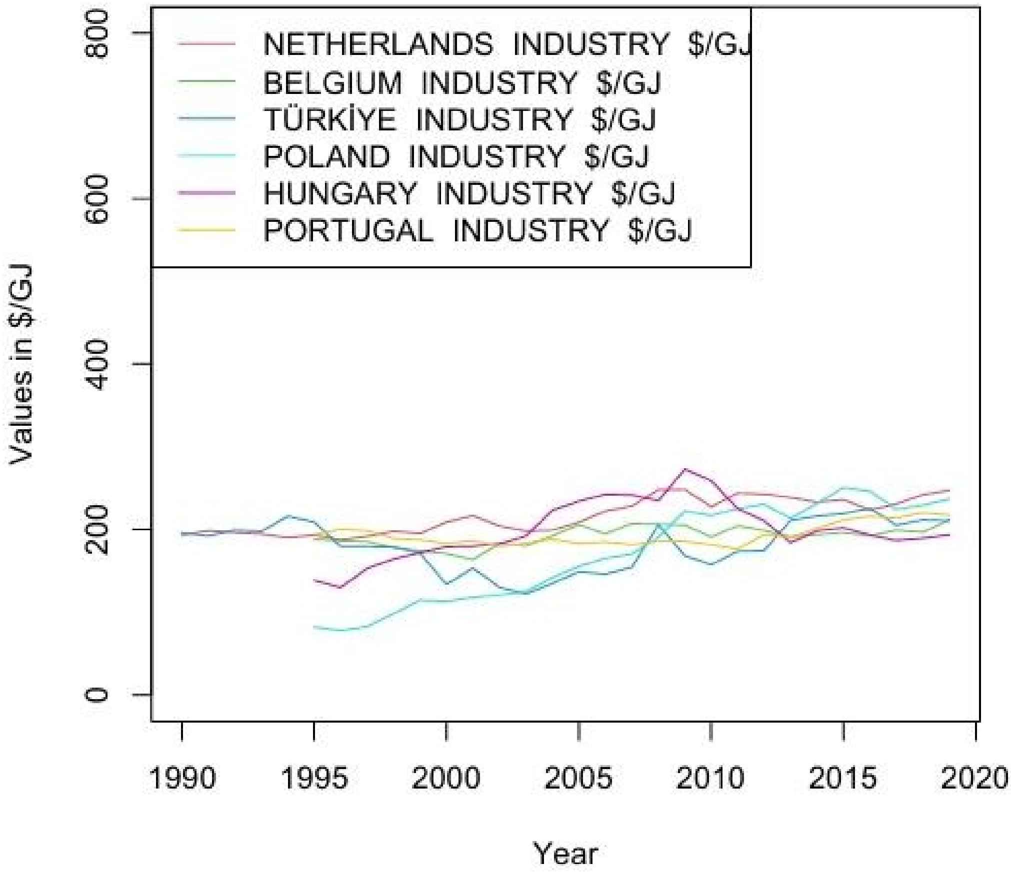

Figure 5.3 Industrial Sector $/GJ in Netherlands, Belgium, Türkiye, Poland, Hungary & Portugal

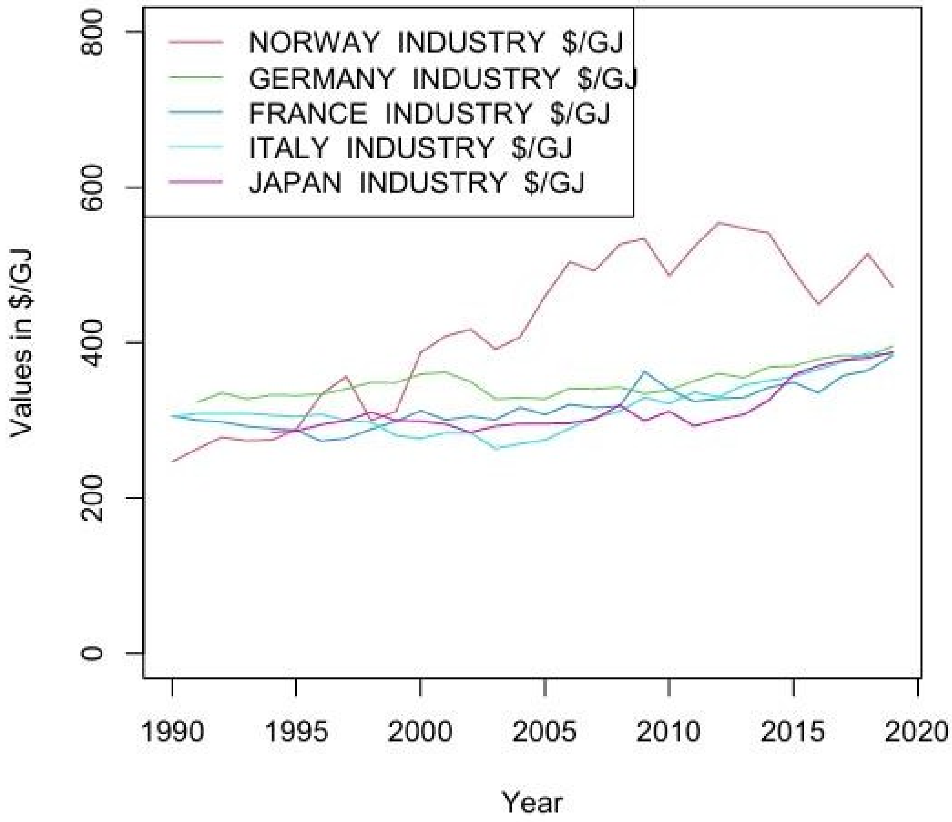

Figure 5.4 Industrial Sector $/GJ in Norway, Germany, France, Italy & Japan

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APPENDICES

A. p-values of Augmented Dickey-Fuller Test for Disaggregated GDP Data for a period 1990-2019

Country	*GDPPC*	*IGDPPC*	*SGDPPC*	*OGDPPC*
Australia	0.9779	0.2636	0.9598	0.4136
Austria	0.8904	0.6938	0.9017	0.5657
Belgium	0.5800	0.5861	0.5419	0.4782
Brazil	0.3595	0.1956	0.1438	0.0100
Chile	0.6227	0.7133	0.4699	0.5745
China	0.5839	0.3679	0.9900	0.5451
Colombia	0.5481	0.4443	0.8223	0.5451
Denmark	0.4253	0.5130	0.4200	0.3023
France	0.5232	0.3994	0.6212	0.7924
Finland	0.6215	0.5401	0.6444	0.4083
Germany	0.3065	0.4832	0.4896	0.3062
Greece	0.4838	0.5681	0.6620	0.5404
Hungary	0.4990	0.6419	0.3762	0.9773
India	0.9900	0.5545	0.9900	0.9900
Indonesia	0.9535	0.5374	0.9586	0.9695
Italy	0.4400	0.4623	0.3625	0.3790
Japan	0.4359	0.8776	0.7199	0.3469
Korea	0.6300	0.5081	0.6185	0.5190
Mexico	0.3884	0.3777	0.08162	0.9253
Morocco	0.7788	0.6543	0.5630	0.8986
Netherlands	0.5030	0.7314	0.4968	0.2930
New Zealand	0.6650	0.2912	0.4564	0.0671
Norway	0.4486	0.9828	0.5465	0.0652
Poland	0.9561	0.4975	0.5967	0.6545

Portugal	0.4505	0.6964	0.3697	0.7046
South Africa	0.9350	0.6220	0.9071	0.2149
Spain	0.3851	0.2943	0.4704	0.5500
Sweden	0.8197	0.7411	0.7756	0.0901
Switzerland	0.2214	0.5384	0.0569	0.7843
Thailand	0.0100	0.5593	0.9166	0.5150
Türkiye	0.6121	0.7228	0.6849	0.0160
United Kingdom	0.4403	0.4392	0.6078	0.2390
United States	0.5902	0.4114	0.7176	0.6538

$p<0.05$ was considered statistically significant

B. p-values of Augmented Dickey-Fuller Test for Disaggregated Energy Consumption Data for a period 1990-2019

Country	*ICPC*	*SCPC*	*OCPC*	*TCPC*	*RCPC*
Australia	0.2660	0.9865	0.4233	0.6271	0.9879
Austria	0.9867	0.5634	0.2040	0.5885	0.3704
Belgium	0.3398	0.7001	0.4595	0.5609	0.3271
Brazil	0.9900	0.0818	0.3561	0.3004	0.2333
Chile	0.8851	0.5512	0.5019	0.0113	0.6575
China	0.2912	0.4370	0.6743	0.2218	0.9415
Colombia	0.5371	0.4519	0.3569	0.9005	0.5747
Denmark	0.3963	0.7069	0.7151	0.5950	0.3077
France	0.5039	0.3886	0.3706	0.5641	0.9297
Finland	0.6331	0.9487	0.6039	0.8825	0.6411
Germany	0.4149	0.9316	0.7134	0.5308	0.0541
Greece	0.4813	0.8682	0.4728	0.4397	0.6301
Hungary	0.9252	0.5046	0.3742	0.4583	0.5214
India	0.7621	0.9593	0.9790	0.6920	0.9591
Indonesia	0.5567	0.7211	0.9484	0.7514	0.9849
Italy	0.4438	0.6819	0.1789	0.6223	0.9414
Japan	0.2642	0.3780	0.3747	0.4664	0.9513
Korea	0.8019	0.0274	0.5283	0.2480	0.7553
Mexico	0.4469	0.0801	0.6378	0.8361	0.0573
Morocco	0.7165	0.5693	0.6167	0.2986	0.6566
Netherlands	0.3292	0.9024	0.7106	0.8771	0.2517
New Zealand	0.3041	0.8832	0.1401	0.4718	0.7936
Norway	0.5914	0.0708	0.8583	0.9478	0.0715
Poland	0.6095	0.9653	0.5898	0.03839	0.1552
Portugal	0.0863	0.5996	0.1650	0.2762	0.5446

South Africa	0.9025	0.5754	0.5591	0.4373	0.3777
Spain	0.5475	0.6427	0.4054	0.1049	0.8359
Sweden	0.1000	0.0996	0.3968	0.9444	0.2932
Switzerland	0.9627	0.9751	0.0124	0.7562	0.7527
Thailand	0.0100	0.7332	0.8836	0.1595	0.7965
Türkiye	0.3919	0.5719	0.6972	0.6573	0.4335
United Kingdom	0.2903	0.0100	0.7646	0.4216	0.8300
United States	0.4829	0.2121	0.6412	0.7373	0.1340

$p<0.05$ was considered statistically significant

C. p-values of Augmented Dickey-Fuller Test for 1st Difference of Disaggregated GDP Data for period 1990-2019

Country	*GDPPC_D*	*IGDPPC_D*	*SGDPPC_D*	*OGDPPC_D*
Australia	0.2200	0.0061	0.1295	0.0237
Austria	0.0188	0.0003	0.1160	0.0009
Belgium	0.0725	0.0001	0.3520	0.0074
Brazil	0.0202	0.0001	0.0002	0.0000
Chile	0.0790	0.0012	0.0244	0.0019
China	0.2820	0.3420	0.1820	0.1570
Colombia	0.1050	0.0312	0.0964	0.0025
Denmark	0.0459	0.0050	0.2650	0.0010
France	0.0400	0.0013	0.1750	0.0019
Finland	0.0065	0.0015	0.0706	0.0004
Germany	0.0016	0.0000	0.0631	0.0011
Greece	0.0685	0.0214	0.0286	0.0216
Hungary	0.4610	0.0272	0.6190	0.0063
India	0.7460	0.1610	0.0526	0.1699
Indonesia	0.1350	0.0026	0.1248	0.0001
Italy	0.0043	0.0007	0.0329	0.0003
Japan	0.0030	0.0039	0.0250	0.0041
Korea	0.1971	0.0505	0.4690	0.0027
Mexico	0.0016	0.0004	0.0022	0.0073
Morocco	0.1990	0.0064	0.0614	0.0001
Netherlands	0.0442	0.0002	0.0913	0.0539
New Zealand	0.0445	0.0003	0.1150	0.0000
Norway	0.0967	0.0002	0.0003	0.0016
Poland	0.7690	0.0501	0.8670	0.0095
Portugal	0.0875	0.0101	0.2040	0.0111

South Africa	0.0114	0.0002	0.0747	0.0000
Spain	0.0674	0.0879	0.1090	0.0038
Sweden	0.0108	0.0001	0.1340	0.0002
Switzerland	0.0192	0.0002	0.1192	0.0005
Thailand	0.1510	0.0502	0.2950	0.0254
Türkiye	0.0387	0.0060	0.0678	0.0044
United Kingdom	0.0833	0.0004	0.0449	0.0022
United States	0.0721	0.0009	0.1970	0.0217

$p<0.05$ was considered statistically significant

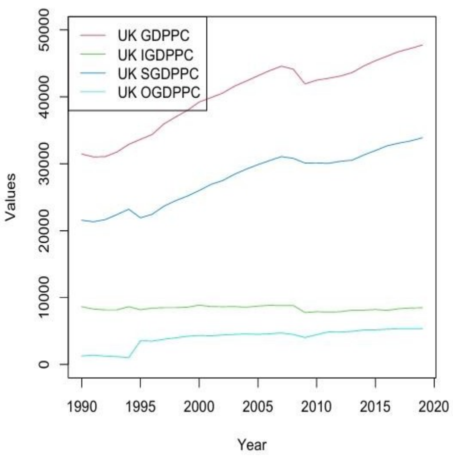
D. p-values of Augmented Dickey-Fuller Test for First Differences of Disaggregated Energy Consumption Data for period 1990-2019

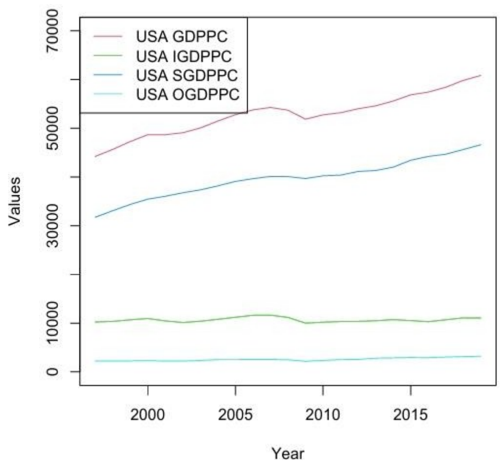
Country	*ICPC_D*	*SCPC_D*	*OCPC_D*	*TCPC_D*	*RCPC_D*
Australia	0.0018	0.0167	0.0003	0.0010	0.0027
Austria	0.0020	0.0043	0.0001	0.0209	0.0000
Belgium	0.0023	0.0001	0.0000	0.0047	0.0001
Brazil	0.0031	0.0708	0.0024	0.0604	0.0028
Chile	0.0006	0.0026	0.0076	0.0648	0.0002
China	0.1030	0.0282	0.0802	0.1340	0.0563
Colombia	0.0000	0.0003	0.0001	0.0002	0.0003
Denmark	0.0067	0.0001	0.0053	0.0048	0.0000
France	0.0000	0.0000	0.0037	0.0019	0.0000
Finland	0.0004	0.0053	0.0004	0.0001	0.0000
Germany	0.0000	0.0008	0.0002	0.0037	0.0000
Greece	0.0018	0.0058	0.0287	0.0247	0.0001
Hungary	0.0156	0.0017	0.0062	0.0832	0.0014
India	0.1380	0.1575	0.0226	0.1840	0.0027
Indonesia	0.0004	0.0300	0.0000	0.0129	0.5720
Italy	0.0153	0.0119	0.0001	0.0065	0.0001
Japan	0.0007	0.0274	0.0001	0.0563	0.0004
Korea	0.0006	0.0071	0.0081	0.0042	0.0027
Mexico	0.0015	0.0001	0.0003	0.0126	0.0096
Morocco	0.0015	0.0005	0.0068	0.3417	0.0087
Netherlands	0.0005	0.0001	0.0002	0.0047	0.0000
New Zealand	0.0014	0.0022	0.0194	0.0303	0.0001
Norway	0.0000	0.0000	0.0005	0.0034	0.0000
Poland	0.0023	0.0660	0.0001	0.0589	0.0058
Portugal	0.0082	0.0042	0.0004	0.0524	0.0575
South Africa	0.0003	0.0012	0.0000	0.0004	0.0001

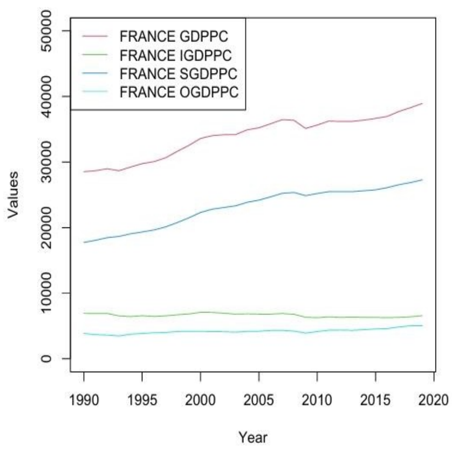
Spain	0.0078	0.0045	0.0099	0.1030	0.0214
Sweden	0.0046	0.0001	0.0000	0.0020	0.0002
Switzerland	0.0055	0.0000	0.0003	0.0027	0.0000
Thailand	0.0247	0.0035	0.0296	0.0156	0.0470
Türkiye	0.0000	0.0111	0.0010	0.0100	0.0001
United Kingdom	0.0158	0.0002	0.0137	0.0064	0.0000
United States	0.0014	0.0001	0.0373	0.0093	0.0001

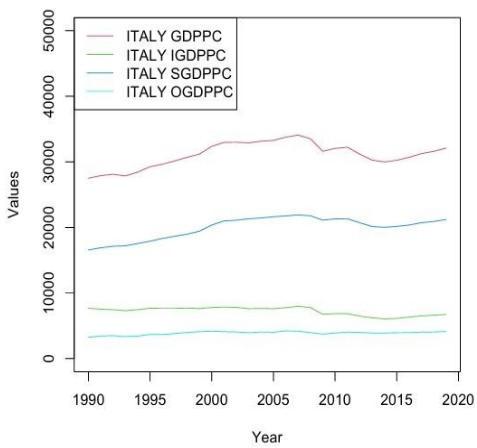
$p<0.05$ was considered statistically significant

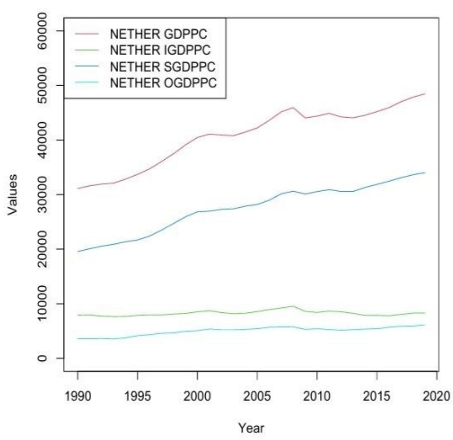
E. Countries That Experience Steady State in Industrial Sector GDP per Capita

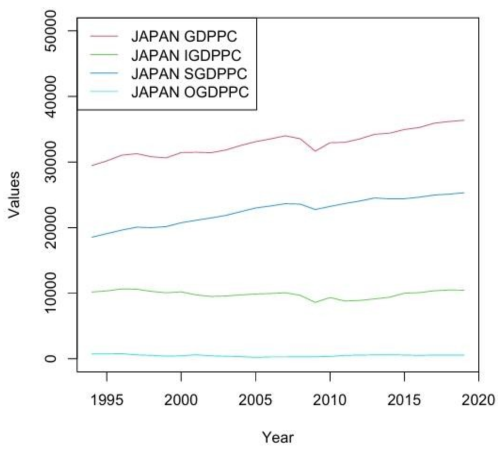












F. Countries with Decrasing TFEC and Increasing GDP