The Impact of Renewable Energy Consumption on Economic Growth: Fossil-Fuels-Dependent Countries

تأثير استهلاك الطاقة المتجددة على النمو الاقتصادي: الدول المعتمدة على الوقود الاحفوري

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List of Abbreviations

AIC	Akaike Information Criterion
ARDL	Autoregressive Distributed Lag
CADF	Cross-section Augmented Dicky Fuller
CES	Constant Elasticity of Substitution
CD	Cross-section Dependence
CIPS	Cross-Section Dependence Im–Pesaran–Shin
CO_2	Cardon Dioxide
ECI	Economic Complexity Index
FEX	Fossil Fuels Exports
FIM	Fossil Fuels Imports
FMOLS	Fully Modified Least Squares
G7	Group of Seven is an inter-governmental political forum consisting of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.
GDP	Gross Domestic Product
GHG	Greenhouse Gases
H_0	Null Hypothesis
H_a	Alternative Hypothesis
K	per Capita Gross Fixed Capital Formation
L	Labor Force Population
LINEX	Linear Exponential Functions
LM	Lagrange Multiplier
N	Number of Cross Sections
n	Number of Observations
OECD	Organization for Economic Co-operation and Development
RE	Electricity generated by renewable energy sources
SDG	Sustainable Development Goals assigned by the United Nations
SH	Slope Homogeneity
T	Time Dimension
VECM	Vector Error Correction Model
Y	GDP per Capita

Abstract

Burning fossil fuels to produce energy has been an essential driver in economic activities for around two centuries. Recently, despite the relatively still growing fossil-fuels consumption, renewable energy sources are being adopted and their share is rising with a higher rate. For the sake of environmental and human health protection, countries are applying new policies to replace fossil fuels with renewables. Although these are valuable steps towards energy security and environmental sustainability, the timing and the intensity of such a switch could harm the economy. Literature on the subject is diverse and growing but it does not provide conclusive results. More specialized studies within specific characteristics may carry better insights. This study addresses the impact of renewable electricity on the economic growth in fossil-fuels-dependent countries whose share of renewables is noteworthy. The study includes panel data from six fossil-fuels net-exporting countries and eight net-importing countries over the period 1995-2019. The study applied unit root tests and co-integration tests that accounts for cross-section dependence and slope heterogeneity. Cross-section dependence has been found among importers but not in exporters. The variables in both models are integrated of order one I(1). Fully Modified Least Squares method uncovered that 1% increase in renewables will increase GDP per capita by 0.08% and 0.10% for exporters and importers respectively. (Dumitrescu & Hurlin, 2012) non-Granger causality test showed that renewables have a bidirectional causal effect on economic growth in exporting countries and importing countries. *feedback hypothesis* for exporters suggests the beneficial effect on the economy due to renewables adoption, hence it is recommended to increase their share. Also *feedback hypothesis* for importers infers that the economic growth has led to a higher renewables' usage, consequently, it is recommended to continue embracing economic growth which is eventually going to promote renewables. This ultimately will lead to achieve climate-change goals and reduce dependence on fuels imports as well.

الملخص

يعد حرق الوقود الأحفوري لإنتاج الطاقة محركًا أساسيًا للأنشطة الاقتصادية منذ حوالي قرنين من الزمان. في الآونة الأخيرة، على الرغم من الاستهلاك المتزايد نسبيًا للوقود الأحفوري، إلا أنّه تم تبني مصادر الطاقة المتجددة بشكل واسع ونصيبها يرتفع بمعدل أعلى. من أجل حماية البيئة وصحة الإنسان، تطبق البلدان سياسات جديدة لاستبدال الوقود الأحفوري بمصادر الطاقة المتجددة. على الرغم من أن هذه خطوات قيمة لتحقيق أمن الطاقة والاستدامة البيئية، إلا أن توقيت وكثافة مثل هذا الاستبدال يمكن أن يضر بالاقتصاد. الأدبيات حول هذا الموضوع متنوعة وفي تزايد ولكنها لا تقدم نتائج قاطعة. قد يكون القيام بالمزيد من الدراسات المتخصصة مؤديا لتقديم تفسيرات أفضل. تتناول هذه الدراسة تأثير الكهرباء المنتجة من المصادر المتجددة على النمو الاقتصادي في الدول المعتمدة على الوقود الأحفوري في تجارتها، والتي في نفس الوقت تنتج حصة لا يستهان بها من الطاقة المتجددة. تضمنت الدراسة بيانات من ستة بلدان مصدرة للوقود الأحفوري وثمانية دول مستوردة للفترة 1995-2019. طبقت الدراسة اختبارات وجود النزعة واختبارات التكامل المشترك بين المتغيرات. تم اختيار فحوص تأخذ بعين الاعتبار تأثر الدول بالصدمات المشتركة وعدم التجانس في عوامل التأثير في النموذجين (المصدرون والمستوردون). المتغيرات في كلا النموذجين متوائمة من الدرجة الأولى. كشفت طريقة **FMOLS** أن زيادة الطاقة المتجددة بنسبة 1٪ ستزيد نصيب القوى العاملة من الناتج المحلي الإجمالي بنسبة **0.08**٪ و**0.01**٪ للمصدرين والمستوردين على التوالي. اختبار (Dumitrescu & Hurlin, 2012) لمعرفة اتجاهات السببية أظهر أن مصادر الطاقة المتجددة لها تأثير سببي ثنائي الاتجاه على النمو الاقتصادي في البلدان المصدرة والمستوردة. تشير فرضية النمو في حالة المصدرين إلى التأثير المفيد على الاقتصاد بسبب تبني مصادر الطاقة المتجددة على مدار السنوات الماضية، لذلك يوصى بزيادة حصة الطاقة المتجددة لزيادة التأثير الإيجابي. تشير الفرضية نفسها أيضا في حالة المستوردين إلى أن النمو الاقتصادي أدى إلى زيادة استخدام مصادر الطاقة المتجددة والعكس صحيح، وبالتالي يوصى بالاستمرار في تبني النمو الاقتصادي الذي سيؤدي في النهاية إلى تعزيز مصادر الطاقة المتجددة وبالتالي تحقيق الأهداف البيئية وتقليل الاعتماد على الاستيراد الخارجي.

1 Introduction

1.1 Preface

Sovereign countries consider the affairs of energy sources matters of national security; thus, they are guarded by highest security measures (Flaherty & Filho, 2013). This high supervision is plausible given the critical role of energy in modern-day society. Energy is an indispensable component within the existing economy; It fuels transportation, it electrifies residential households, and it powers all sorts of industries. Therefore, most countries around the globe aim to maintain a stable flow of energy into their economies. Energy sources should be firmly secured so that the production and consumption systems of goods and services can run smoothly and continuously. One of the 17 Sustainable Development Goals (SDG) set by the United Nations is ensuring access to affordable, reliable, sustainable, modern energy for all (United Nations, 2021). On the other hand, international pacts like Kyoto protocol and Paris agreement were signed on by most countries to face the climate change issues caused by traditional energy usages like fossil-fuels consumption. The undesirable global warming effects has already started to distress environment ecosystems, health of humans, and economic activities (Vogel, 2017; Almuhisen & Gökçekuş, 2018).

On the domestic level, each country has set national goals to reduce greenhouse gases (GHG) and CO_2 emissions. This reduction requires substituting CO_2-emitting sources like coal, oil and natural gas with renewable energy sources like hydro, solar, and wind. The switch from fossil-fuels to renewables could serve countries to achieve energy sustainability and have a cleaner environment. However, this comes with a substantial initial cost because of the required investments to build renewables' infrastructure (Kibria et al., 2019). There is also a need for innovation in renewables' technologies to increase output efficiency and improve distribution systems. On the contrary, Fossil-fuels have been favorably efficient in terms of energy production. They also have convenient consumption and transfer networks, making them an easy viable choice (Timmons et al., 2014).

Regarding fossil-fuels resources, countries divide into three groups. First, Countries with massive reserves that exceed their domestic needs so they export the rest of production to other countries. They may depend heavily on these exports to generate income. Second, Countries with high demands for fossil-fuels and don't have enough reserves, so they mainly depend on imports from producing countries. Third, countries with moderate demands or moderate reserves. These countries could be importers or exporters, but they don't depend excessively on fossil-fuels trade to run their economies.

In countries with a high dependency on fossil fuels, policymakers are eager to know how energy sources should be evaluated to estimate their future impact. But given the ambiguity on how all previous factors might affect economic performance, an examination of the relationship between each type of energy and the economic growth is crucial. Configuration of desirable energy ecosystems requires policy recommendations to take into account three points. The strong craving for sustainable affordable energy, fossil-fuels level of dependence. And in the same time monitoring the negative externalities of taking a specific path like adopting renewables as an alternative.

Categorized under Energy Economics, several studies have been conducted to understand how energy and its different sources interact with the economy elements. Research has focused on drivers of economic output, specifically, capital formation, labor force and total energy. The addition of non-renewable and renewable energy formulates the research of disaggregate energy-economic growth nexus (Omri, 2014; Cvijović et al., 2020a). What is new in this research is the focus on fossil-fuels-dependent economies. These countries will be widely affected if policy makers take a different path in the energy sector. Because a huge part of the economy is running with a specific configuration, adopting a new source of energy will disrupt the current economic activities. Therefore, this change should be investigated before applying related policies. In this study, we examine the impact of this change in energy sector in fossil fuel-based economies.

1.2 Problem Statement

Currently, the use of fossil fuels to run a wide range of economic activities is clearly indispensable. However, given the negative externalities of these fuels, the necessity to switch to cleaner energy sources is increasing; Policy makers in most countries are in a growing need for an evidence-based guidance to take the right decisions; Renewables' promoting policies are increasingly being applied as a result of governments international commitments. They are also being employed to achieve energy security. Oppositely, a significant number of fossil fuels advocates argue that a drastic shift to renewables might obstruct economic performance. The debate arises intensely in fossil-fuels-dependent economies, where such a sizable change means a structural modification in the economic activities. Countries who depend heavily on income from fossil fuels need to recognize how different policies would affect the economy. Also, Countries who import a large share of fossil fuels to run the economy need to identify the impact of promoting one energy source over the other. Given previous needs, this study addresses the problem of energy sources impact for each group of countries, and apply the suitable methods to conclude data-driven recommendations. Literature's conclusions in this field have mixed recommendations, but most of our studied research indicates the positive impact of renewable energy on the economy.

1.3 Study Purpose

The study aims to uncover the impact of renewable electricity consumption on the economic growth in fossil-fuels-based economies. The study examines the relationship between renewables consumption levels and GDP per capita in fossil-fuels net exporting/importing countries. In the selected countries, the share of fossil fuels exports/imports exceeds 20% of total exports/imports, and the share of renewables to generate electric power is more than 5% for exporters and 15% for importers. Six net exporters and eight net importers have been selected based on the previous criterion. The research also intends to discover the possible relationships between fossil-fuels exports/imports and economic growth in each group of countries. The results of this research will include the causality directions and the degree of influence between the target variables.

1.4 Study Questions

To achieve the purpose of this study we should be able to provide answers for the following questions.

1- What is the causality connection between renewable electricity consumption and GDP per capita in fossil fuels net-exporting countries and net-importing countries?
2- What is the magnitude of influence of renewable electricity on economic growth in the two groups of countries?
3- What is causality connection between fossil-fuels exports/imports and GDP per capita in the two groups of countries?

4- What is the magnitude of influence of fossil-fuels exports/imports on economic growth in the two groups of countries?

1.5 Study Importance

The significance of this study can be expressed along two axes. **Firstly**, the type of selected countries in the study is rarely studied; The literature on RE-GDP nexus has considerable gaps in fossil-fuels-dependent economies. To our knowledge, this type of countries has not been covered specifically except in two studies by Kahia et al. (2016, 2017). This type of countries is important because the effects of the switch from non-renewable to renewable energy sources can be observed clearly; Their high dependence on fossil-fuels makes the shift to renewables more obvious and the consequences more evident. **Secondly**, the key difference between Kahia et al. (2016, 2017) and this study is that we included countries where renewables share of total electricity is significant. Countries like Saudi Arabia, Oman, and UAE are not included because their renewables share is too small to impact the economy. Contrarily, our selected countries have a share of renewables to the level where the impact on the economy is notable and statistically significant.

1.6 Study Plan

The research is organized in the following three sections. Section **two** contains an exploration of previous studies about the renewable energy-economic growth nexus. The selected studies covered several methodologies and various countries within different time periods. Section two extends **to** contain the theoretical framework that validates the methodology of this research. The section also illustrates the context of the selected countries, presenting the main characteristics of each country. Section **three** explains the methodologies and the econometric techniques employed in the study. Section **three extends** to display empirical results and outputs' analysis. Section **four** wraps up all the information obtained from the study to comprehend the over-all conclusion and recommendations. Section **five** includes the references.

2 Literature Review & Theory

2.1 Literature

Research on total energy-economic growth nexus has accumulated over the past five decades. Since Kraft & Kraft (1978) had addressed the empirical correlation between both variables, the research has followed thoroughly and extensively. Hence, some governments have taken these studies as a supporting argument to promote certain policies (Gallagher, 2013). Yet in most countries, research couldn't deliver conclusive results (Ucan et al., 2014). Moreover, considering disaggregate energy consumption, probable correlation between renewable energy consumption (RE) and economic growth has notified researchers to fill the gaps in renewables' area. The rise of renewables' share in total energy motivated such research. Cvijović et al. (2020) provided an extensive literature review on the relationship between RE and economic growth, the paper demonstrated the rising interest in this relationship and its prospects in different economies.

Mainstream studies of energy-growth nexus were mainly conducted to measure the impact of total energy on economic growth. A wide range of studies have been done to investigate the relationship between the two variables, the results were typically expected to support one of four hypotheses (growth, feedback, conservation, and neutrality). Likewise, renewable energy-economic growth research has the same four hypotheses. Firstly, growth hypothesis, which assumes a unidirectional causality from RE to GDP. Consequently, a RE conservation policy may harm economic growth (Payne, 2010). Secondly, feedback hypothesis which assumes that the direction of impact works in both ways, RE changes GDP, and GDP changes RE, this is a dynamic interchanging relationship, where the two variables are jointly affected (Ozturk, 2010). Thirdly, Conservation hypothesis, where the change in GDP will cause a change in RE, this relationship works in one direction from GDP towards RE (Rahman & Velayutham, 2020). Finally, the neutrality hypothesis, it assumes that there is no casual effect between the two variables (Payne, 2010).

2.1.1 Growth Hypothesis

It implies that increasing consumption of renewable energy will positively affect economic growth, the relationship runs in one direction from RE to GDP. It indicates that supporting-renewables policies will eventually lead to economic growth. Fang (2011) studied the Chinese renewables impact on economic growth in the period 1978-2008. The study concluded that 1%

increase in RE increased GDP per capita by 0.162%. Despite its low participation, study findings for an emerging economy like China in that period indicates a strong developing correlation between the two variables. Additionally, RE is forecasted to affect economic welfare in the medium-term.

Using (Emirmahmutoglu & Kose, 2011) causality test, Chang et al. (2015) confirmed the growth hypothesis in France, Canada, and Japan. Based on 18 Latin American countries' data over the period 1980-2010, Al-mulali et al. (2014) found one way positive effect of RE on GDP growth in the long run. Covering the period 1990-2011, Halkos & Tzeremes (2014) studied a sample of 36 countries by implementing non-parametric analysis, the paper revealed a non-linear increasing causal effect from RE to GDP in 'Advanced-Developed Economies'. In the U.S., Bilgili (2015) applied continuous wavelet coherence methodology to be able to observe the frequency dimension of the related variables. The researcher found that RE has a unidirectional positive impact on economic growth. Table 1 lists additional notable studies that support Growth Hypothesis.

Table 1 Growth Hypothesis Literature

#	Author(s)	Period	Countries	Methodology
1.	(Dogan, 2015)	1990-2012	Turkey	ARDL, Johansen Cointegration test, Gregory–Hansen cointegration test with Structural break (long run)
2.	(Hamit-Haggar, 2016)	1991-2007	8 new EU countries	Asymmetric causality test, ARDL
3.	(Alper & Oguz, 2016)	1990-2009	Tunisia	Asymmetric causality test, ARDL
4.	(Destek & Aslan, 2017)	1980-2012	Peru	Bootstrap panel causality
5.	(Ito, 2017)	2002-2011	42 developed countries	Generalized method of moments (GMM), pooled mean group (PMG) technique, (long run)
6.	(Amri, 2017b)	1980-2012	Algeria	ARDL
7.	(Koçak & Şarkgüneşi, 2017)	1990-2012	Bulgaria & Greece	Heterogeneous panel causality
8.	(Bao & Xu, 2019)	1997-2015	China: 4 provinces	Bootstrap panel causality test
9.	(Maji et al., 2019)	1995-2014	15 West African countries	Panel dynamic ordinary least squares (DOLS) (Negative Impact))

2.1.2 Feedback Hypothesis

Several studies have shown that the impact of RE on economic growth can be accompanied with an impact of economic growth on RE, this relationship asserts the feedback hypothesis. It infers that a boost in economic growth will increase renewable energy consumption. It also means that promoting renewables will increase economic growth.

According to Apergis et al. (2010), there is a bidirectional causality between RE and economic growth in 19 developed and developing countries. While Kahia et al. (2016, 2017) studied 11 net oil importing countries and 13 net exporting countries, and confirmed the feedback hypothesis in the long run. The studies indicate that the expansion of renewable energy not only can moderate the dependence on fossil fuels imports for import dependent economies, it also can minimize the risk associated with volatile oil and natural gas supplies and prices.

The extensive work of Apergis & Payne (2010a, 2010b, 2011a, 2011b, 2012) and Aydin (2019) concluded a bidirectional casual effect between the two variables. The results strongly support the feedback hypothesis and the mutual interchanging relationship between renewables consumption and economic growth. Using ARDL and Vector Error Correction models, Bildirici & Özaksoy (2013) found a bidirectional causal link between biomass RE and Economic growth in Spain, Sweden, and France. Covering a range of developing and developed countries, (Pao & Fu, 2013; Sebri & Ben-Salha, 2014; Rafindadi & Ozturk, 2017; Alvarado et al.m 2019) studied China, Russia, India, Germany, South Africa and several Latin American countries. They found a bidirectional Granger causality relationship between RE and economic growth supporting the feedback hypothesis. The studies infer the stimulating role of RE on economic growth in these countries.

Given previous studies, we realized that income of each set of countries seems to affect the clarity of RE impact on economic growth; The higher the income the clearer that RE has a larger effect on the economy.

In the following, a table of additional notable studies that support Feedback Hypothesis.

Table 2 Feedback Hypothesis Literature

#	*Author(s)*	*Period*	*Countries*	*Methodology*
1.	(Shahbaz et al., 2015)	1972Q1-2011Q4	Pakistan	ARDL, Rolling widow approach (RWA), VECM Granger causality
2.	(Ibrahiem, 2015)	1980-2011	Egypt	ARDL
3.	(Chang et al., 2015)	1990-2011	G-7 Countries	The Emirmahmutoglu and Kose causality methodology.
4.	(Destek & Aslan, 2017)	1980-2012	Greece & South Korea	Bootstrap panel causality
5.	(Amri, 2017a)	1990-2012	72 countries	Dynamic-simultaneous equation panel data approach
6.	(Koçak & Şarkgüneşi, 2017)	1990-2012	Albania, Georgia, & Romania	Heterogeneous panel causality

7.	(Saad & Taleb, 2018)	1990-2014	12 European Union countries	Granger causality, Panel vector error correction model
8.	(Zafar et al., 2019)	1990-2015	APEC countries	Westerlund cointegration test, Continuously Updated Fully Modified Ordinary Least Square (CUPFM)

2.1.3 Conservation Hypothesis

The hypothesis assumes that economic growth leads to an increase in renewable energy consumption. The relationship between the two variables follows a causal link from GDP to RE, as a result, policies that support increasing renewables consumption might not improve GDP. However, directing more economic growth will increase renewables consumption and this eventually will achieve energy sustainability. Sadorsky (2009a, 2009b, 2011b) studied G-7 and 18 emerging countries, the author uncovered a unidirectional causal effect from GDP to RE in the both types of economies (developed and developing). In Turkey, Destek (2016) and Ocal & Aslan (2013) implemented Toda-Yamamoto causality tests to uncover a **negative** unidirectional causality running from GDP to RE. It means that economic growth decreases renewables usage in Turkey, therefore, economic development led to more consumption of CO_2-emitting sources. Azlina et al. (2014) investigated the case of Malaysia and found that income (GDP) Granger-causes RE and non-RE, which is in favor of the conservation hypothesis for both types of energy. Rahman & Velayutham (2020) applied FMOLS and panel causality test to reveal a causal effect running from GDP to RE in five south Asian countries.

2.1.4 Neutrality Hypothesis

Neutrality hypothesis implies that there is no casual connection between economic growth and renewable energy consumption, in this case, the relationship between the two variables indicates that any change in policies regarding one variable may not impact the other.

Bowden & Payne (2010) asserted the existence of a unidirectional causality from residential renewable energy and GDP in the US, but found no casual effect between industrial and commercial renewable energy and GDP. Neutrality hypothesis is confirmed by Menegaki (2011) covering 27 European countries. Using multivariate panel framework, The no-causation relationship between economic growth and renewable energy may be explained by the uneven and insufficient exploitation of renewable energy sources in that period. Al-mulali et al. (2013) found that 19% of the studied countries are categorized under neutrality hypothesis. In Brazil, despite the bidirectional relationship between RE and GDP in the short run, Pao & Fu (2013) found no causal effect between the two variables in the long run.

2.1.5 General Overview

Numerous researchers have conducted empirical studies to assess the relationship between RE and GDP in multiple-country dataset using panel data analysis. Single-country research is less common in this field due to lack of wide span of data, unless there is sufficient data like in the U.S. (Salari et al., 2021); Most papers have covered multiple countries to overcome this barrier. However, in most of studies, selection criteria are not clear. A number of researchers studied a single region because of national motives or for the sake of homogeneity (Magnani & Vaona, 2013; Valodka & Valodkienė, 2015; Lehr & Ulrich, 2017). Other researchers included large set of countries to increase study validity and exploit the power of panel analysis (Apergis & Payne, 2011b; Halkos & Tzeremes, 2014; Le et al., 2020). While other researchers based their studies on groups of countries with particular characteristics. Kahia et al. (2016, 2017) studied RE and GDP within net oil exporting and importing countries respectively. While Furuoka (2017) focused research on Baltic countries which have similar economic structures. In addition, several authors covered countries within international classifications, Hung-Pin (2014) included a number of OECD countries to study the relationship between RE and GDP. Chang et al. (2015) investigated the same relationship in G7 countries. While Ozcan & Ozturk (2019) focused on emerging economies.

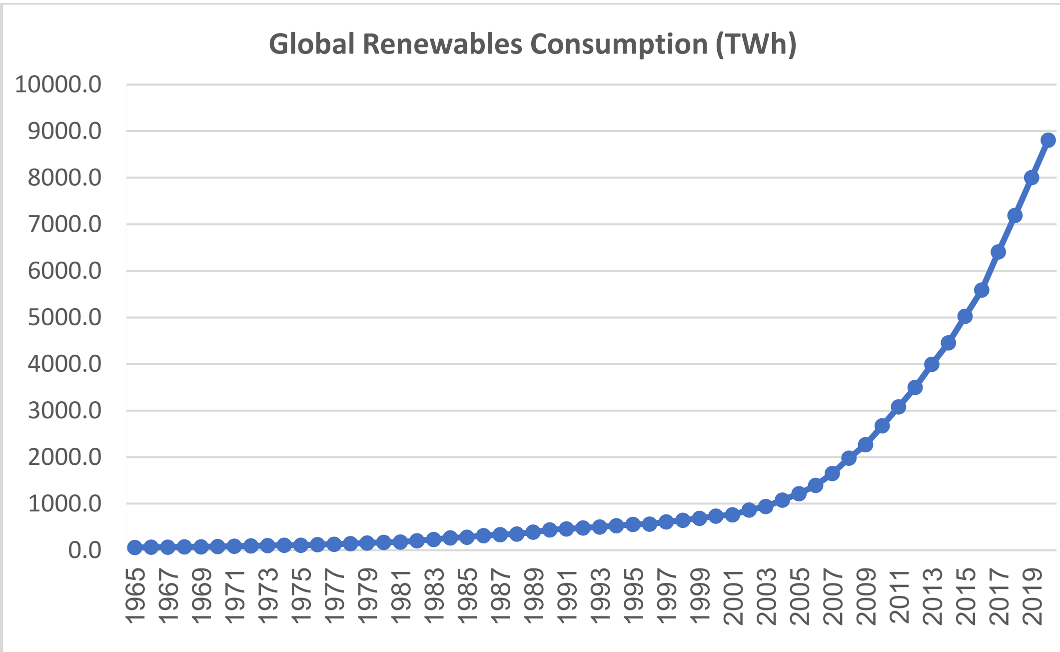
The observer may find some papers involve the same group of countries and yet diverge in conclusions and suggestions, the following table includes parts of these contradictions or agreements.

Country	*Author(s)*	*Period*	*Methodologies*	*Result*
China	(Fang, 2011)	1978-2008	Multivariate OLS	Growth
	(Lin & Moubarak, 2014)	1977-2011	ARDL, Johansen cointegration, Granger Causality	Feedback
	(Bao & Xu, 2019)	1997-2015	Bootstrap panel causality test	80% Neutrality
USA	(Bowden & Payne, 2010)	1949-2006	Toda-Yamamoto procedure	Residential-only Growth
	(Yildirim et al., 2012)	1949-2010	Toda-Yamamoto procedure and bootstrap-corrected causality test	Biomass only Growth
	(Salari et al., 2021)	2000-2016	OLS and GMM	Growth
OECD countries	(Apergis & Payne, 2010a)	1985-2015	Panel cointegration, ECM, Granger Causality	Feedback

(Shafiei, 2013)	1980-2011	DOLS, CCE, GMM	Feedback
(Hung-Pin, 2014)	1982-2011	ARDL, ECM	Mixed results for sub-groups inside OECD

Table 3 Differences in Literature

The table exemplifies how studies may integrate with each other to support a specific policy similar to the case of OECD countries. And how they may increase unclarity about the relationship between the two variables like in the case of China. In the case of USA, more integral studies may conclude decisive results. One of the reasons behind these differences is the use of different econometric methodologies. Similarly, periods' selection may affect research empirical results and therefore its final suggestions. Significant changes can occur in certain time periods which may not be covered, these changes will not be included in the study too. Figure 1 illustrates the steep increase in global renewables consumption after the year 2012.



Data source: BP Statistical Review of World Energy 2020

Figure 1 Global Renewable Energy Consumption 1965-2019 (TWh)

Researchers also put attention on variables' selection to formulate fitted models. The major variables in this subject are GDP or GDP per capita and Electricity Renewable Energy (RE) (Sadorsky, 2009b; Aydin, 2019). Labor Force population (L) and Gross Fixed Capital Formation (K) are also essential variables and have been included in most of studies to avoid omitted-variable bias (Apergis & Payne, 2010a). In addition, some researchers integrated other variables; Bowden & Payne (2010), Apergis & Payne (2012), and Al-mulali et al. (2014) included non-renewable energy consumption in their models to compare the impact of renewables and non-renewables sources on the economy. Apergis et al. (2010) inserted nuclear energy variable to cover more sources. Silva et al. (2012), Cherni & Essaber Jouini (2017), Cai et al. (2018), and Saidi & Omri (2020) included CO_2 emissions as a key variable in their studies. The importance of CO_2 presence lies in the fact that one of the major motives to adopt renewables is to reduce greenhouse gases (CO_2 and others).

2.2 Theoretical Framework

2.2.1 Renewable Energy in Economics

Energy definitions may vary according to source and context. Generally, scientists defined energy as the ability to do physical work (Kent, 1916). In economics, energy is a primary input in most of economic activities. It is also essential to sustain the modern human lifestyle, which is partly instrumented by the human development index (HDI) (Wang et al., 2021). Absence of energy would definitely affect HDI negatively.

Demirel (2012) described energy forms and sources in detail, the article classified energy types into primary and secondary. Primary energy consists of two main categories, renewable energy which includes waste, solar, wind, hydro, biomass, and geothermal. And non-renewable energy, which includes all fossil fuels (oil, coal, and natural gas) and nuclear power. The secondary energy is the transformed primary inputs which are used for final consumption. Figure 2 explains energy types and illustrates energy sources.

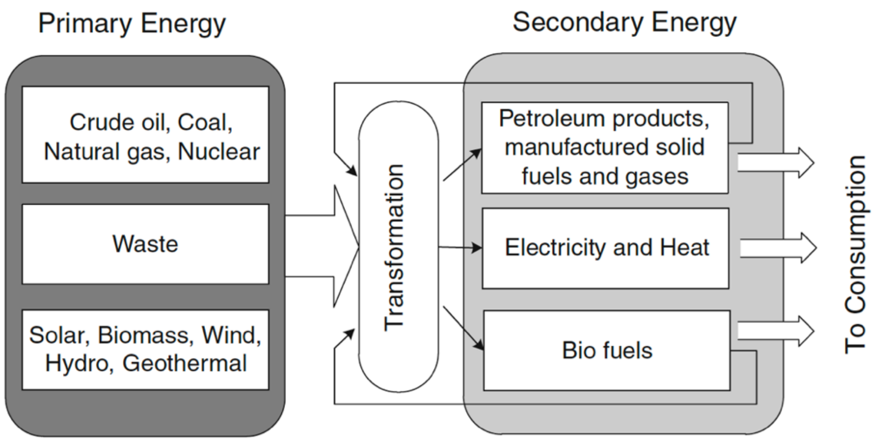


Figure 2 Energy Types and Sources

According to (Mishra, 2007), scientists studied production functions since the publication of Cobb & Douglas (1928) to understand economic output evidently. Later on, Solow (1956) and Swan (1956) had independently presented the technical development factor in the Cobb-Douglas production function. The factor represented the impact of technological progress on economic output. Regarding energy variable, in 1973, the massive impact of oil embargo against the U.S. had prompted economists to consider including the energy variable in production functions (Mishra, 2007). Given the change of economic performance due to the energy crisis, it became clear that a significant share of production was resulted from energy incorporation. In addition, the technological advancements required the use of unprecedented amounts of energy (Goldemberg, 1992). Therefore, the energy variable has been associated with the Solow-Swan productivity factor and within the production function as well.

Kümmel et al. (1985) affirmed that energy consumption is a factor of production as fundamental as capital and labor. They argued that neither capital nor labor can perfectly substitute the energy role in the modern economy. The study applied different production functions on data from Germany and the U.S. to observe the impact of energy consumption on the economic output. Along with LINEX and CES functions, a Cobb-Douglas energy-dependent function was employed to prove that the real data curves are closely matching the theoretical curves. Therefore, energy consumption values have been denoted by energy variable in production functions.

Energy-focused research tried to fit energy variable in the production function accurately (Georgescu-Roegen, 1986). Hence, energy variable had been incorporated in a broad range of studies to discover the role of energy consumption in production models (Faucheux, 1993). This finding has been asserted by Mishra (2007) explaining the history and the scientific arguments which support energy variable insertion. Extending Cobb & Douglas (1928) function with regard to the Solow-Swan model and energy inclusion, the modified production function is shown in Eq. (1).

$$Y_{it} = A_i K^{\beta_{1i}} L^{\beta_{2i}} E^{\beta_{3i}} \quad (1)$$

Where Y is GDP, A is the technical development in production, K is the gross capital formation, L is the labor force population, E is energy consumption, $i = 1, 2\ 3, \ldots$ stands for the number of the selected cross-section unit, and t stands for time.

Kümmel et al. (1985) followed by Lindenberger & Kummel (2002) have asserted firmly on the validity of energy inclusion in production functions. They also noted that despite its limitations, the most used function in macroeconomic analysis is the Cobb-Douglas production function. The rise of renewables' share from around 7% of total energy consumption in the late 1990s to more than 11% in 2019 has raised economists' attention (Saidi & Omri, 2020). The scientific research has become more inclined to measure the potential impact of renewables on economic output. Renewable energy is playing a major role to replace the conventional energy sources. This shift is increasingly pushing different economic sectors to integrate unconventional manufacturing and transportation methods in operations (Shafiei, 2013). As a result, it is implied that RE is creating a novel part of economic output. In addition, since total energy variable is a factor of production function, the disaggregated renewable and non-renewable sources are also factors of production (Kahia et al., 2017). Consequently, economists have justified the inclusion of renewable energy consumption in production functions. Ewing et al. (2007), Sadorsky (2009a), and (Apergis & Payne, 2010a) have included renewable energy in GDP models to study the impact of RE on economic growth. Several studies have followed this path to examine the impact of RE on economic growth using the augmented Cobb-Douglas production function. It is represented in Eq. (2)

$$Y_{it} = A_i K^{\beta_{1i}} L^{\beta_{2i}} NE^{\beta_{3i}} RE^{\beta_{4i}} \tag{2}$$

Where Y is GDP per capita, A is the technical progress, K stands for capital formation, L is labor force, NE stands for non-renewable energy consumption, RE stands for renewable energy consumption, $\beta_1, \beta_2, \beta_3, and\ \beta_4$ are the elasticities of output with respect to each variable, and i = 1,2,3, … stands for each country or cross-section unit.

2.2.2 Fossil Fuels Role in Economic Growth

All types of coal, petroleum, and natural gas are classified as fossil fuels. These hydrocarbons are produced in living organisms by the process of photosynthesis or biosynthesis, which convert solar radiation into chemical energy (Soysal & Soysal, 2020). Fossil fuels have been one of the main reasons behind the swift economic growth in the last 150 years, they powered the industrial revolution and the related advancements that followed (Carbonnier & Grinevald, 2011). We can observe from Figure 3 the sizable share of fossil fuels in the mix of global energy consumption.

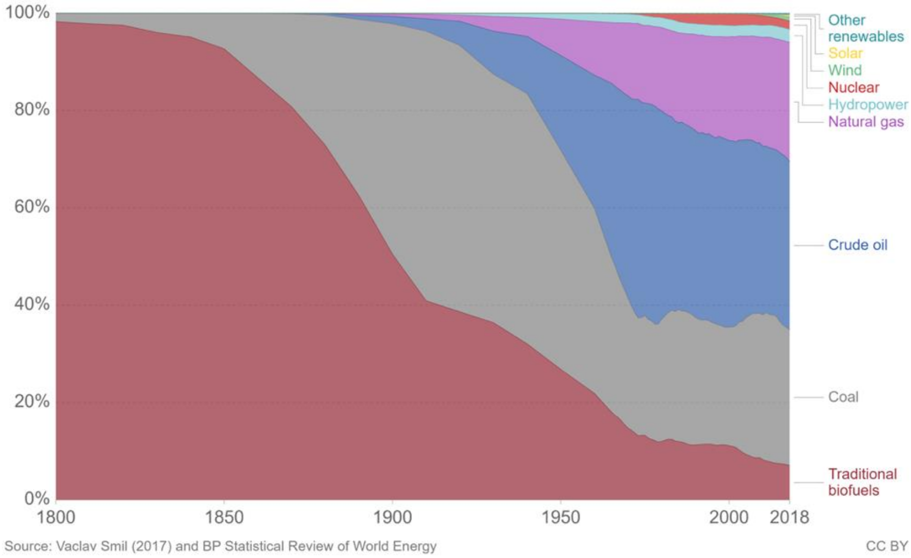


Figure 3 Global Energy Consumption Mix

Currently, more than 80% of world energy comes from fossil-fuels. A huge adoption of fossil-fuels has occurred due to the relatively cheap prices, and due to the established and efficient transfer and consumption networks (Carbonnier & Grinevald, 2011). Therefore, the transition from fossil fuels to other alternatives is highly challenging. In addition, The economic growth is affected considerably by fossil fuels production, trade, and consumption because they dominate the energy sector (Kibria et al., 2019); The usage of non-renewable fuels is the primary source of residential electricity. Moreover, The dependence of most of industrial countries on fossil fuels is substantial; Manufacturing and transportation largely rely on these fuels to operate (Leatherby & Martin, 2019).

Countries which import coal, oil and natural gas the most are troubled by prices fluctuations and supply chain instability (Baláž et al., 2020). Furthermore, most of other goods supply chains are affected either directly or indirectly by fossil fuels (Rout et al., 2008). In regards to exports, major net-exporting countries depend critically on fossil fuels revenues to run the economy and cover the government's budget deficit. Exporting countries which more than 20% of their direct income comes from fossil fuels are considered economically vulnerable (Coren, 2021). Price shocks, decreasing demand rate, and renewables rise can be tough on economies with such structure. There is also a socio-economic factor affecting both exporters and importers where several groups of employees mainly depend on jobs within the fossil-fuels' industry (Tvinnereim & Ivarsflaten, 2016).

Given previous factors, the impact of fossil fuels exports/imports on economic performance is worth considering. In regards to total trade, Mo (2010) concluded that most studies suggest a positive causal impact of international trade on economic growth. Accordingly, the more the weight of fossil fuels within total trade, the more the impact they apply on the economy (Mercure et al., 2018).

The imported goods and services into a country can be used and utilized to generate economic output by producing valued goods and services. Furthermore, imports might replace domestic production which can affect economic growth negatively. Therefore, in both situations the inclusion of imports variable in an augmented Cobb-Douglas production function sounds reasonable and applicable (Damooei & Tavakoli, 2006; Herrerias & Orts, 2013). On the other hand, exports stand as a source of direct income where its impact linkage on economic output is not straight forward. Therefore, scholars who included exports variable in the Cobb-Douglas model had four arguments. Firstly, exports growth reflects the increase in demand of country's outputs. Thus, new channels of demand will be created, this in turn will be realized in a rise in production and more economic growth (Jung & Marshall, 1985; Zaman, 2016). Secondly, exports' income increases foreign exchange reserves, this facilitates the purchasing of intermediate productive goods. As a result, the capacity of different industries expands resulting in a rise in economic output (Onafowora et al., 1996; Kónya, 2006). Thirdly, exports' rate affects the level of total factor productivity; In fact, the growth of exports motivates technical improvements in production leading to economies of scale. Oppositely, large exports of few categories of goods might affect economic growth negatively due to low diversification of investments (Feder, 1983; Medina, 2001). Finally, exports' earnings might form a budget surplus and serve the country's debt. Therefore, the burden of debt will be reduced allowing production elements to operate with less friction to sustain economic growth (Kollie, 2020).

Given previous reasonings, (Waithe et al., 2010; Simuț, 2015; Sultanuzzaman et al., 2019) have employed the Cobb-Douglas production function to examine the impact of exports on economic growth.

Concerning fossil fuels' trade, countries with large shares of fossil fuels in trade might find a considerable impact of this trade on economic growth. As we discussed previously, exports and imports are justified to be included in an augmented Cobb-Douglas function. Likewise, the inclusion of fossil fuels' exports or imports sounds more plausible in fossil-fuels-based economies. In net-exporting countries, fuels' exports provide the economy with the needed funds to cover debt and to purchase advanced technologies for production. These conditions assist the country to be financially independent and to be relatively more productive, which in turn leads to economic growth. In net-importing countries, an increasing fuels' share in total imports reflects a rise in production rate. Shahbaz et al. (2013) has addressed these matters using an extended Cobb-Douglas model. The study examined the impact of exports and natural gas consumption on economic growth in France. Natural gas consumption represented to a large extent the fossil fuels imports because France is a net-importing country. Another study by Hosseini & Tang (2014) has included oil & non-oil exports and total imports to measure their impact on economic growth in Iran. They used Eq.3 as a model for estimation.

$$\ln Y_t = \beta_0 + \beta_1 lnOX_t + \beta_2 lnNOX_t + \beta_3 lnK_t + \beta_4 lnL_t + \beta_5 lnIM_t + \varepsilon_t \quad (3)$$

Where "ln" is denoted as the natural logarithm, t is the year, Y is gross domestic product, OX is export of oil and gas products, NOX is export of non-oil products, K is the capital investment, L is the labor force participation, and IM is total imports of goods and services. The usage of such variables in economic growth models can help us recognize new perspectives about economic growth in specific countries.

2.3 Research Context

This study has been based on two concepts. Firstly, the literature validation of RE inclusion in economic growth models. Secondly, fossil fuels trade (exports and imports) has been also validated to be included in the production function. Countries differ in their fossil-fuels dependence, thus their vulnerability to external shocks varies.

Countries which fit in our context have two characteristics. First, they are highly dependent on fossil fuels' imports or exports. E.g. Lin & Xu (2020) considered China's case to clarify the level of dependence on fossil fuels as an importer. Second, they have a notable share of renewables in electric power generation. In summary, these countries are under an external pressure; their economic growth is disturbed by fuels prices, political stability, and new energy innovations. On the other hand, they have the ability to uplift their established renewables share and diversify income streams to avoid economic crises (Charfeddine & Barkat, 2020).

We selected countries that reflect the mentioned criteria to conclude customized recommendations. Exporting countries have two attributes. On average, they depend on fossil fuels exports to generate more than 20% of net exports value. On average, they also generate more than 5% of electric power from renewable energy sources. Oppositely, importing countries have two attributes with different direction and quantity. They depend profoundly on fossil fuels to run the economy; On average more than 20% of imports are fossil fuels. Regarding RE, they generate more than 15% of electric power from renewables. The reason why we selected different RE percentages among the two groups is that exporters usually delay the adoption of renewables. Because of the large reserves of fossil fuels they have, their incitive to increase RE share is lower. On the contrary, importers look for alternatives to avoid the uncertainty of fossil fuels trade.

We included six exporting countries: Australia, Canada, Indonesia, Iran, Mexico, and Russian Federation. And eight importing countries: China, France, Germany, India, Italy, Japan, Spain, and Thailand.

2.3.1 Fossil-Fuels Net-exporting Countries

In this section, we will highlight some of the important characteristics of exporting countries. As previously mentioned, selected exporting countries have average renewables share of more than 5% of total electricity production. Figure 4 illustrates the share of RE in each country over the target period.

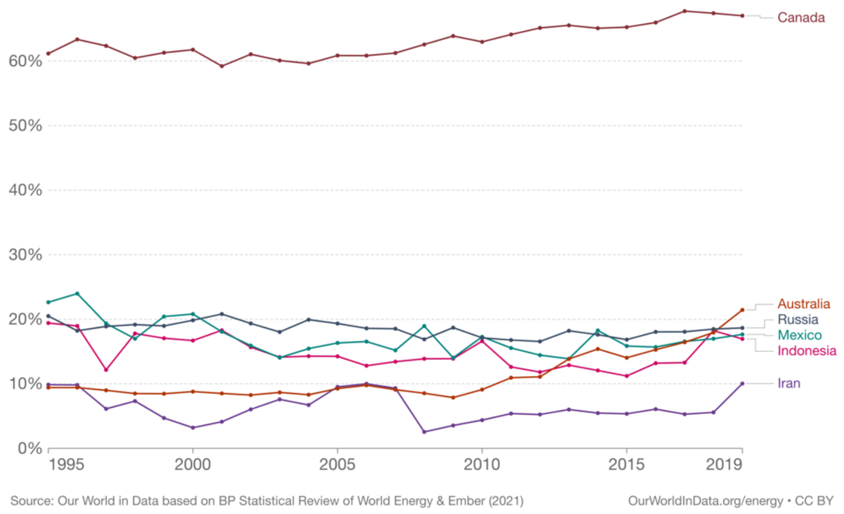


Figure 4 Share of electricity production from renewable sources (Exporters)

Australia is a highly developed country with a noteworthy dependence on fuels exports. Figure 5 shows that more than 28% of exports were fossil-fuels in the last ten years. While from Figure 4, we notice that the renewables share of total electricity has increased from less than 10% to over 20% in the same period. Solar and wind have been the primary drivers in more than doubling renewable generation expansion over the last decade. The renewables adoption rise reflects Australia's commitment to Kyoto Protocol and later the Paris Climate Change agreements (Thornton, 2020). Although the country's exports of natural gas and coal exceeds oil imports by a high margin, the high dependence on oil imports put the country under the external pressure of oil markets shocks. This might be another reason behind the rapid adoption of renewables.

The Australian economy is led by the service sector which is valued at nearly 62.7% of GDP in 2017. The country has enormous reserves of crude materials like gold and silver which also consist a significant share of exports. These factors assisted the country to achieve steady economic growth over a long period of time. The available economic capacity might be an additional incentive to invest in renewables and reduce CO_2 emissions.

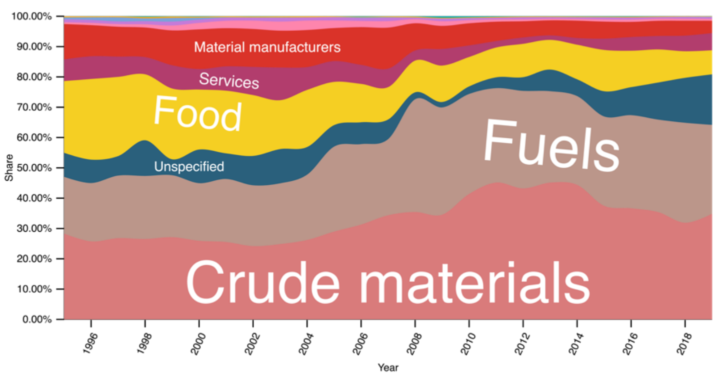


Figure 5 Types of Exports from Australia (% of Total)

Canada has the highest electricity renewable share across the selected countries. In 2019, 68% of electric power came from renewables. This high percentage is a result of the efficient power generation from moving water (hydroelectricity). Moving water is the most significant renewable energy source in Canada, supplying 60% of Canada's electricity demands. In fact, in 2018, Canada was the third largest producer of hydroelectricity in the world. Energy regulations is in favor of renewables too. The federal Renewable Fuels Regulations require fuel producers and importers to have an average renewable share of at least 5% based on the volume of gasoline that they produce or import, and at least 2% of the volume of diesel fuel that they produce and import (Canadian Government, 2019). In addition, Canada has set a goal of increasing the share of zero-emitting sources to 90% by 2030 (Ye, 2018). It is unlikely for a fossil-fuels exporter to have such a substantial adoption of RE. However, Canadian culture and standards have supported the progressive protection of environment and pushed towards clean energy investment. The other primary reason for the large share of RE is the long-ago established systems of hydroelectricity plants. One of the plants is still being used since 1898 (Canadian Hydropower Association, 2009).

Canadian economy has similarities with Australian economy; it is highly developed mixed economy dominated by the service sector as it values 70% of real GDP in 2017. Besides that, fossil-fuels exports form around 30% of Canada's total exports which is 9% of real GDP. Although this is a considerable dependence. The country is heading towards more diversification to prepare for possible fuels price shocks. Further research is needed to understand the relations among previous factors.

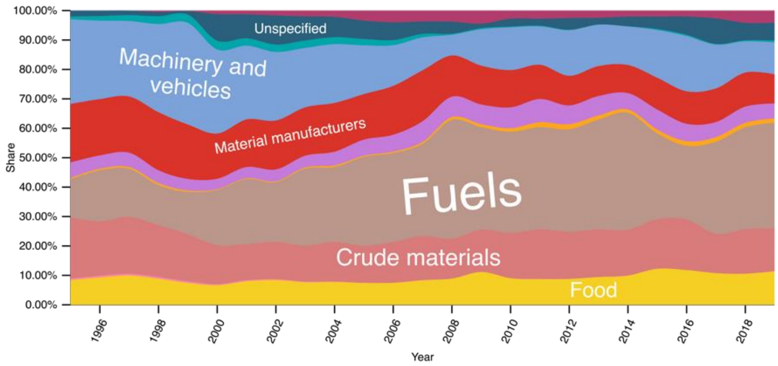


Figure 6 Types of Exports from Canada (% of Total)

As an upper-middle income country and member of the G20, **Indonesia** is classified as a newly industrialized economy. Like Australia, Indonesia is an oil net-importer but fossil-fuels exports (mainly coal) exceed oil imports by a high margin, making the country a fossil-fuels net exporter. Figure 6 demonstrates that fossil-fuels exports consist a weighty share of total exports. In 2019, 6.2% of GDP was created by fossil-fuels exports. The Indonesian economy is 7th largest in terms of GDP (PPP). It has been growing 4-5% a year for over two decades except for 1997's crisis and when COVID-19 pandemic in 2020 stroked most of the world economies. Renewables contribution to electricity generation has been going up and down over the past 25 years. Despite this, RE share has been more than 12% across the whole period, which is a considerable percentage in energy sector for a large country like Indonesia. Moreover, the country has set out to achieve 23% renewable energy use by 2025, and 31% by 2050 (Hartono et al., 2020), (Malik, 2021).

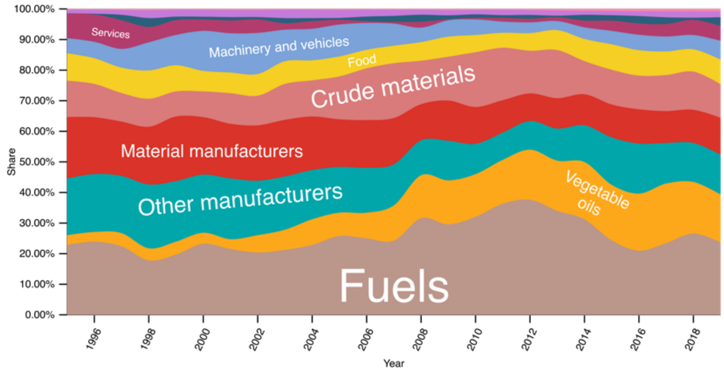


Figure 7 Types of Exports from Indonesia (% of Total)

Considered as an "Energy Superpower", **Iran** has been forecasted to become one of the top fifteen countries in terms of real GDP. On the contrary, Iran has suffered consecutive declines in different time periods in the last 30 years. This is mainly caused by the U.S. sanctions initiated as a result of political conflicts. As we can notice from Figure 8, the major exporting good in Iran is fossil-fuels. This high dependence on oil & gas exports made the country highly vulnerable to external pressure as in the case of U.S. sanctions. Observing Figure 4, although the country has a considerable RE, Iran fluctuated its renewables share in electric power production with no signs of progression. This might be as a result of change in priorities over the years, trying to solve the most pressing issues facing the country like high unemployment and instability of international trade.

Due to its favorable geographic characteristics, Iran has diverse and accessible renewable sources, which offer suitable substitutes to reduce dependence on fossil fuels. regulations and policies might be necessary to exploit these advantages, and decision makers would be motivated if RE is proved to advance the economic growth (Solaymani, 2021).

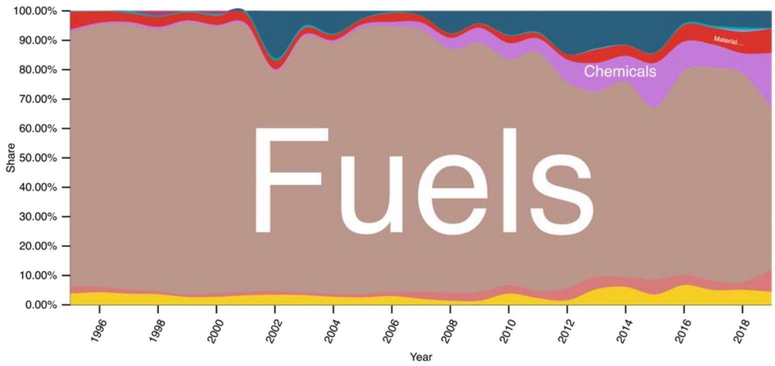


Figure 8 Types of Exports from Iran (% of Total)

Mexico is the least dependent on fossil fuels exports among our selected countries, yet in 2019, 5% of GDP consisted of fuels exports. The Mexican economy is mixed and developing, with domination of automotive industry whose standards of quality are internationally recognized. Real GDP of Mexico has been growing overall but with association of some major declines. Regarding electricity generation from renewables, the share of RE has moved back and forth staying around 17%. These swings in RE investments and adoption may have affected or been affected by the inconsistent economic growth at some points. Major issues like pollution, poverty and energy security is increasingly considered in parallel with economic growth strategies (Mele, 2019). The study proceeds to investigate the relationship between GDP and RE. A potential impact of renewables on the economy may help mitigate the stated issues.

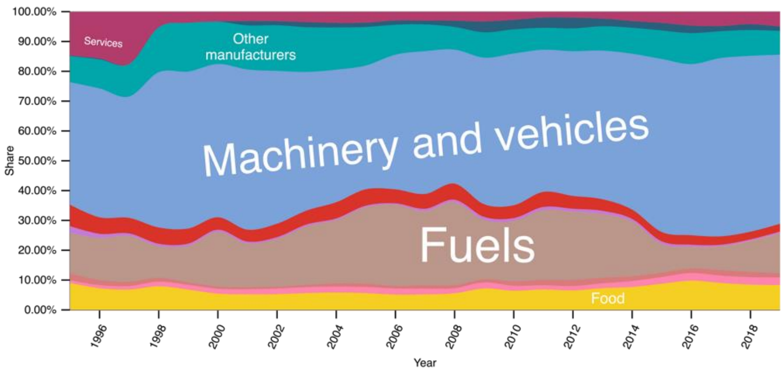


Figure 9 Types of Exports from Mexico (% of Total)

The last fuels-exporting country in our study is one of the global superpowers which plays a major role in the world's politics and economics. **Russia** is the largest country by area and the 6th in the world by real GDP (PPP). Regarding its energy sector, in 2019, 17% of GDP came from fossil-fuels exports. Figure 10 displays the large fuels share of total exports. The country is highly dependent on oil & natural gas exports to generate income. The whole economy is affected by a great deal when fuels prices decline; Sectors' diversification seems to be necessary to lessen this dependence. In regards to renewables adoption, Russia is the ninth-largest energy producer in 2019. When it comes to RE share, it has not been increasing significantly over the selected period. This might be as a result of available & affordable fossil fuels, as a result, the total increase in electricity appears to be provided by more production from traditional power plants (Pagliaro, 2021). Examination of renewables impact in the country might create insights on the promising benefits of RE adoption.

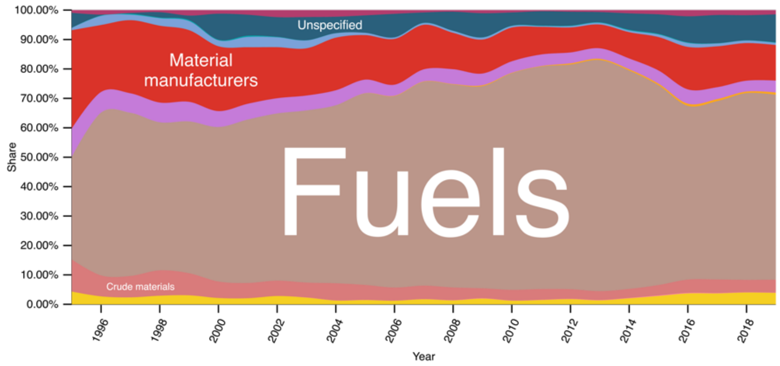


Figure 10 Types of Exports from Russia (% of Total)

2.3.2 Fossil-Fuels Net-importing Countries

In this section, we will highlight some of the important characteristics of importing countries. As previously mentioned, selected importing countries have average renewables share of more than 15% of total electricity production. Figure 11 illustrates the share of RE in each country over the target period.

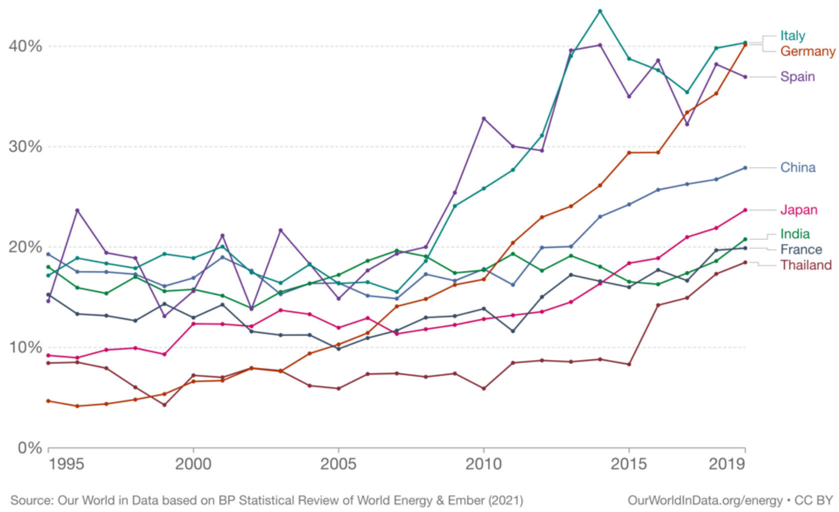


Figure 11 Share of electricity production from renewable sources (Importers)

China is the biggest fossil-fuels importer in the world. In 2019, 17% of the imported fuels in the world have been consumed by China. The country has experienced a swift economic growth because of the unique boosted industrialization and the expansive trade openness. This led China to become the 2nd largest economy in the world. With such a massive economic development, there is an increasing demand for energy to run the economy and cover the growing population essentials.

Due to the shortage in domestic resources to meet these massive fuels needs, more than 20% of China's imports consist of fossil fuels products. In 2019, 21% of China's imports were fossil fuels. Figure 12 shows this weighty share, which pushes policy makers and country strategists to think of finding internal alternatives to protect the ongoing economic growth. As a result, China has been significantly shifting to adopt clean energy in electricity production to moderate fuels imports. Electricity generated from renewables was around 19% in 1995, by the year 2019 it reached around 27%. An 8% increase over 25 years seems modest, but given the huge growth in total power demands over that period, this share is equivalent to 40% of total electricity consumption of the U.S. in 2019. Investigating renewables effect on the economy is required to verify the suitable policies for such a huge economy.

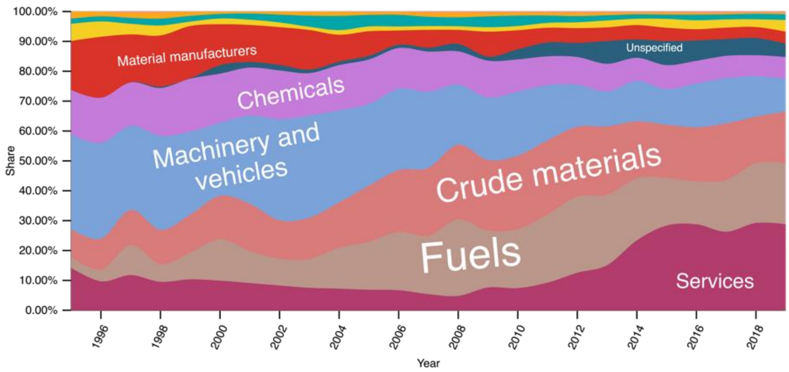


Figure 12 Types of Imports in China (% of Total)

Germany, France, Italy, and Spain are highly developed countries run by liberal democracies. Their economies operate under the European Union economic umbrella and within its institutional regulations. However, each country has its own attributes. Germany is the most developed with the highest GDP per capita of around 46K US dollars in 2019, and with the highest living standards. The country is the de facto leader of the European Union and its most powerful industrial arm (Brinded, 2016). While Spain is the last among the four countries in terms economic performance, GDP per capita is around 29K US dollars, with a high unemployment rate of 15% in 2019. France and Italy are between these ranges. Regarding fossil-fuels consumption, the four countries are highly dependent on fuels imports, Figures 13 ,14 , 15, and 16 illustrates the share of fossil-fuels imports in France, Germany, Italy, and Spain respectively. Averages of shares over the selected period for the four countries exceed 20% of total imports.

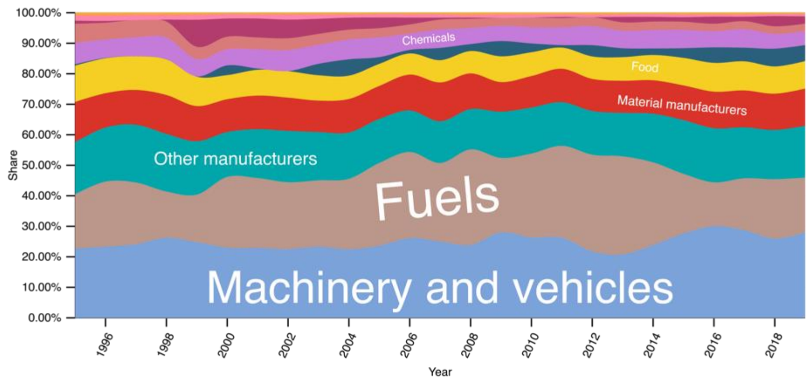


Figure 13 Types of Imports in France (% of Total)

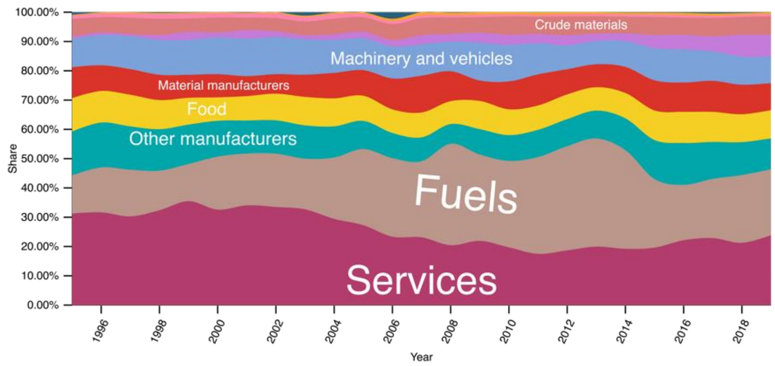


Figure 14 Types of Imports in Germany (% of Total)

The four countries as all other EU countries are committed to Kyoto protocol and Paris agreement. European Parliament voted in February 2014 in favor of binding 2030 targets on renewables, GHG emissions, and energy efficiency: a 40% cut in greenhouse gases, compared with 1990 levels; at least 30% of energy to come from renewable sources; and a 40% improvement in energy efficiency (Harvey, 2014). We can notice from Figure 11 that Germany, Spain, and Italy have increased their renewables share markedly, but France appears to swing at around the same percentage. Despite the interconnected goals set for the EU to achieve, each country has its own national action plan, which is affected by internal factors and may not co-move with other countries' national plans (European Commission, 2021). Accumulation of targeted studies on the impact of renewables use may help decision makers to take further informative steps.

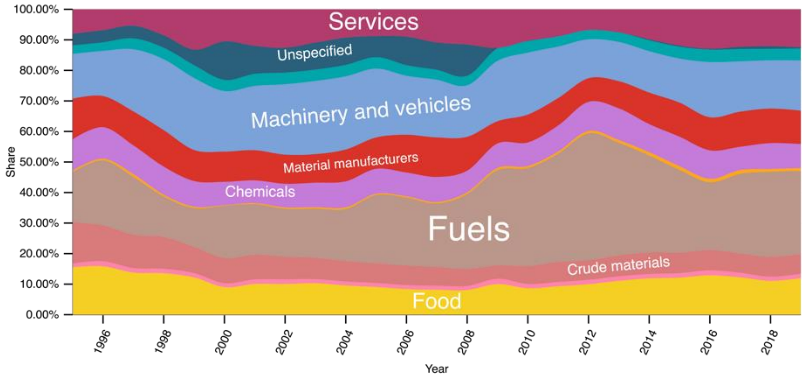


Figure 15 Types of Imports in Italy (% of Total)

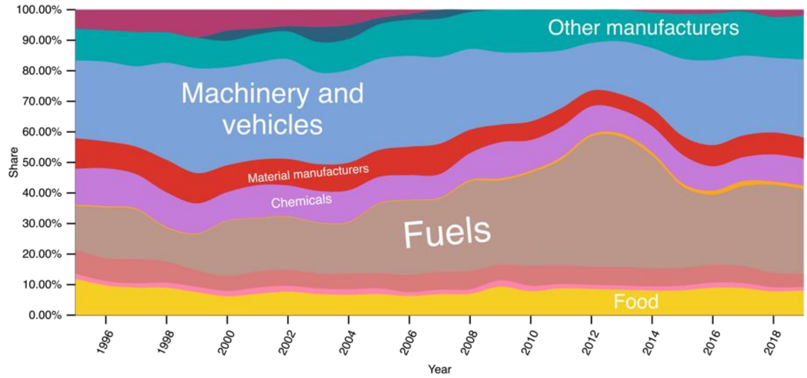


Figure 16 Types of Imports in Spain (% of Total)

Japan is the fourth largest economy in the world by real GDP, and the first in Economic Complexity Index (ECI). ECI is an indicator of the country's product diversification and unique ability to produce products that other countries can't. Despite that, Japan's economy experienced relative declines across the selected period due to the burst of assets prices bubble in 1990s. Economic stagnation was followed and the country couldn't drive economic growth as planned. The slow pace of economic growth in Japan is accompanied with natural resources scarcity, making the country a large net-importer of fossil-fuels. Figure 17 shows the share of fuels imports out of total. It is clear that Japan is greatly dependent on fossil-fuels imports to run its unique economy. This fact made the switch to renewables a necessity. Therefore, Japan has increased its electricity generated from renewables around two and a half folds over the indicated period (Figure 11). On 3 July 2018, Japan's government pledged to increase renewable energy sources, including wind and solar, from 15% to 22–24% by 2030. This goal includes electricity and all other energy uses. Deliberate targets and policies are required to untangle Japan from external dependence.

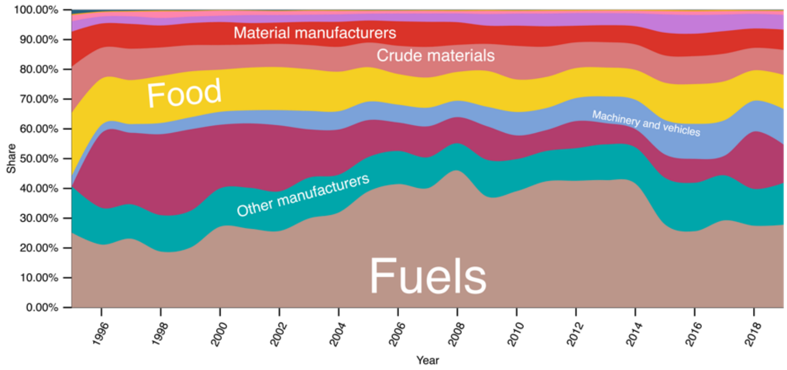


Figure 17 Types of Imports in Japan (% of Total)

India has the 2nd largest population in the world after China, it is one of the fastest growing economies and the 3rd economy in terms of real GDP. However, the country's GDP per capita is one of the lowest globally, more growth is anticipated to overcome poverty, unemployment and pollution. India is highly dependent on fossil-fuels imports to fulfill its large population demand and run its industrial sector which forms around 30% of the real GDP. Figure 18 shows us the high percentage of fuels among imported goods. Given previous conditions, in 2016, in its nationally determined contribution under the Paris Agreement, India has a target of achieving 40% of electric power from non-fossil fuel sources by 2030. Taking the overall progress in renewables adoption in India (Figure 11), these targets seem unattainable. Economic-growth-based adoption of renewables may motivate companies and institutions to take vigorous steps to meet those targets. As a result, more research is required to evaluate the impact of RE on the economy.

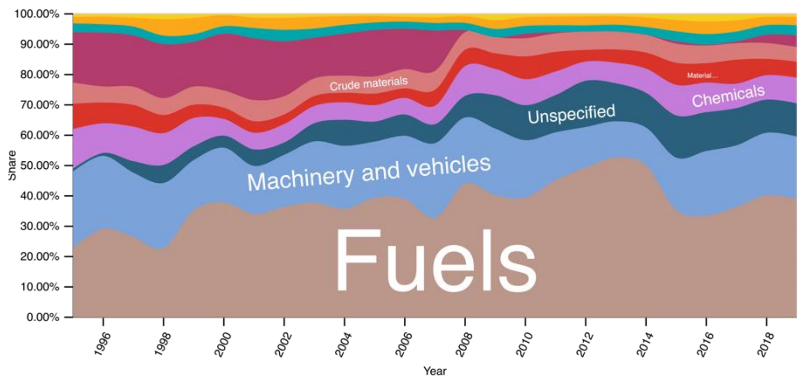


Figure 18 Types of Imports in India (% of Total)

Thailand is a newly industrialized economy with a heavy dependence on exports to generate income. In fact, by the 2019, 60% of Thailand's GDP came from exports. The country is efficiently interconnected with the world. After a long period of low income and high poverty, industrialization with trade openness assisted Thailand to become the 8th largest economy in Asia by the year 2018. From Figure 19, we can observe the relatively growing imports of fossil-fuels. Given the industrial growth occurring in the country and the low levels of domestic resources, such dependence might even increase in the medium term to produce more goods and services ready to be exported. Accordingly, the government has set a goal to increase the proportion of electricity generated by renewables to 40% by 2037. Figure 11 shows that Thailand has increased its renewables share form 8% at the beginning of the interval to 18% in 2019. Given this progress Thailand appears to follow these goals effectively.

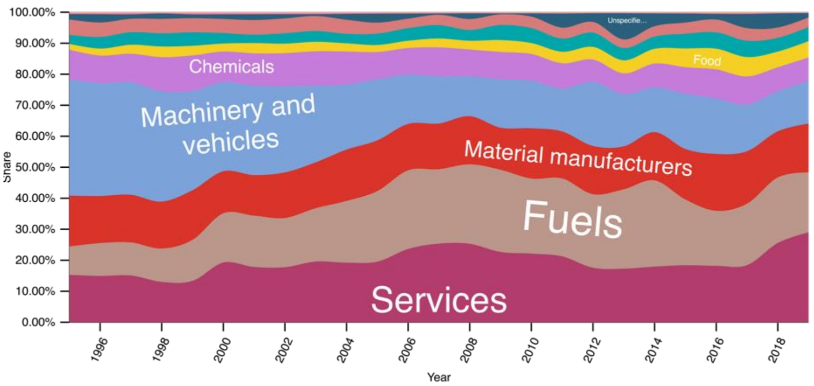


Figure 19 Types of Imports in Thailand (% of Total)

3 Econometric Modeling

3.1 Model & Data

Based on (Apergis & Payne, 2011a), (Shafiei, 2013), (Al-mulali et al., 2014), (Chang et al., 2015), and (Azam et al., 2021), we employed a production model that integrates Renewable Electricity Consumption (RE) associated with Capital Formation (K). In addition, we added Fossil Fuels Exports/Imports (FEX/FIM) representing non-renewable energy trade for both datasets (exporters and importers), because 97.6% of non-renewable energy sources are fossil-fuels (*Energy Data Explorer*, 2021). More specifically, we extend the neoclassical Cobb-Douglas production function by adding both renewable and non-renewable energy factors. It may assist our understanding of the impact of one variable in the presence of the other (RE in presence of FEX or FIM). The inclusion of capital factor is incorporated in the model to control for potential omitted variable bias. We divided all variables in the production function by Labor Force (L) to make some of the characteristic differences between countries more homogeneous within each group. The following equations represent the two models we used in this study. Eq. 4 for exporters, Eq. 5 for importers.

$$\ln Y_{it} = \beta_0 + \beta_1 lnK_{it} + \beta_2 lnRE_{it} + \beta_3 lnFEX_{it} + \varepsilon_{it} \quad (4)$$

$$\ln Y_{it} = \gamma_0 + \gamma_1 lnK_{it} + \gamma_2 lnRE_{it} + \gamma_3 lnFIM_{it} + \varepsilon_{it} \quad (5)$$

Annual data for the period 1995-2019 were obtained from The World Bank DataBank, UN Comtrade Database and BP Statistical Review 2021. The modified production model includes GDP per Labor in constant prices of 2010 U.S. dollars (Y_{it}), Gross Fixed Capital Formation per Labor in constant prices of 2010 US dollars (K_{it}), The divided-by term Total Labor Force (L_{it}), Electricity Consumption from Renewable Sources Terra Watt hours per Labor (RE_{it}), Fossil Fuels Exports per Labor in constant prices of 2010 US dollars (FEX_{it}), Fossil Fuels Imports per Labor in constant prices of 2010 US dollars (FIM_{it}), ε_{it} is the error term, and β_0 and γ_0 are the intercepts.

The data has been organized to fit the two models' specifications. The dataset of exporters panels includes the variable FEX, and the dataset of importers panels has the variable FIM.

The variables have been converted to natural logarithmic form to enhance data stability. It also simplifies the interpretation of statistical results by treating coefficients as elasticities. Each variable name starts with "L" to represent the logarithmic form namely, LY, LK, LRE, LFEX, and LFIM. We expect that fuels exports/imports, renewable energy and capital formation will have positive coefficients in both models.

3.1.1 Data illustration

The major focus of this study is to understand the relationship between renewables adoption and economic growth in fossil-fuels-dependent countries. the following figures illustrate the paths of the related variables over the period 1995-2019. The figures also help in the comprehension of some econometric outputs. For exporter countries, the figures 20, 21, and 22 display the tracks of LY, LRE , and LFEX over the selected time period.

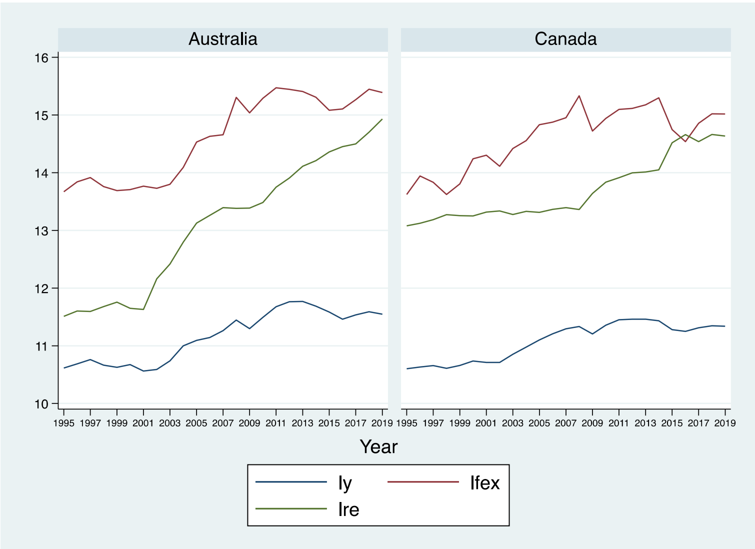


Figure 20 Economic Growth, Renewable Electricity, & Fossil-Fuels Exports over Time in Australia & Canada

Observing Exporters' figures, we notice that all net-exporting countries have relatively increased renewables consumption per labor across the selected period. Economic growth has also risen significantly in all exporter countries except Iran, which ends the period with a small increase comparing to the beginning. The low unstable growth in Iran might be as a result of external political conflicts affecting trade openness and economic activities. This also can be realized by the sharp decline in fossil fuels exports in the last four years in Iran. On the other hand, other exporter countries have significantly improved fossil fuels exports over the selected period which has been realized in an increase in GDP per capita. We can also observe a clear correlation between economic growth and renewable energy consumption in the selected countries.

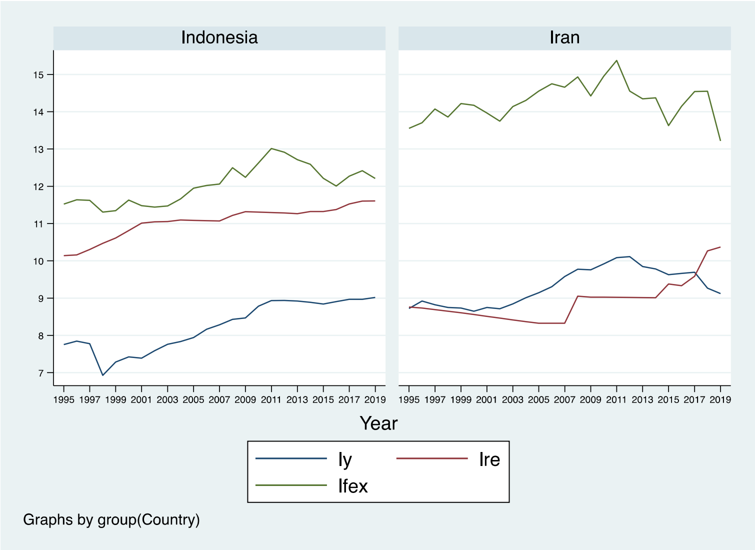


Figure 21 Economic Growth, Renewable Electricity, & Fossil-Fuels Exports over Time in Indonesia & Iran

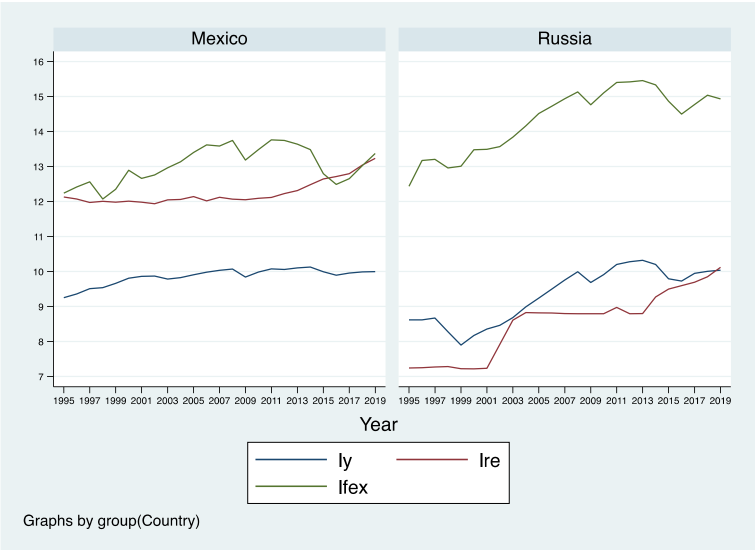


Figure 22 Economic Growth, Renewable Electricity, & Fossil-Fuels Exports over Time in Mexico & Russia

For importing countries, the figures 23, 24, 25, and 26 exhibit the three variables behavior over the selected time period. We can notice that all importers have increased renewables levels per labor over the twenty-five years. China appears to be the leader country by economic growth rates. China's GDP per labor was around 1000 USD in 1995, by the year 2019, GDP per labor has reached around 18,000 USD. In Germany, France, Spain, and Italy economic growth has moved upward at a slower pace. Thasiland and India have experienced a rapid economic growth but it is still lower than China by a medium margin. Japan seems to have several declines with slowly improving economic growth over the same period.

The fossil fuels imports appear to be correlated with economic growth. From economics point of view, industrial countries consume more fossil fuels when economic activities are expanding. Therefore, imports will increase and economic growth might also rise if the allocation of imported resources lead to efficient economic performance.

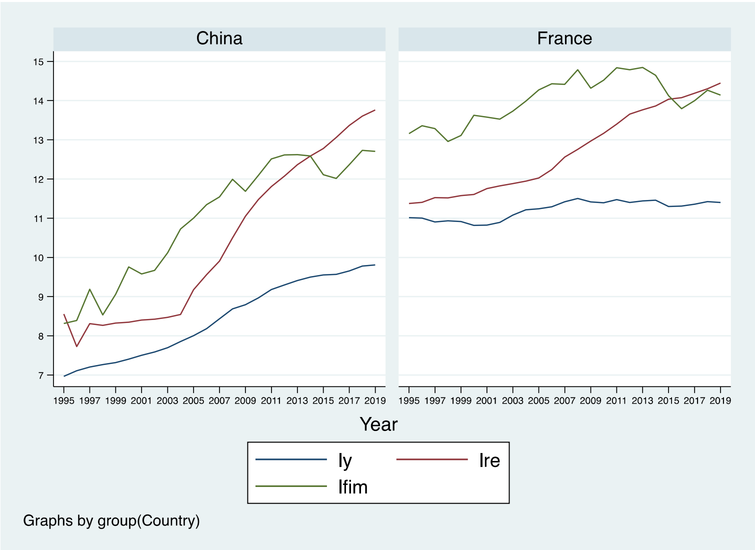


Figure 23 Economic Growth, Renewable Electricity, & Fossil-Fuels Imports over Time in China & France

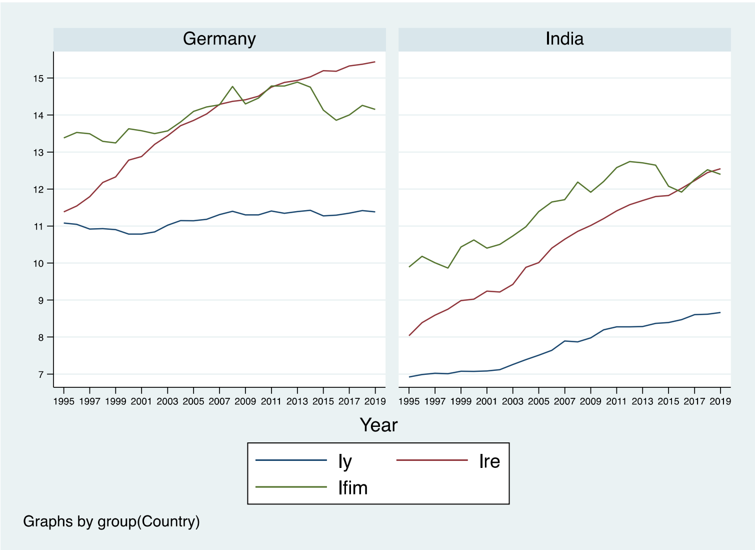


Figure 24 Economic Growth, Renewable Electricity, & Fossil-Fuels Imports over Time in Germany & India

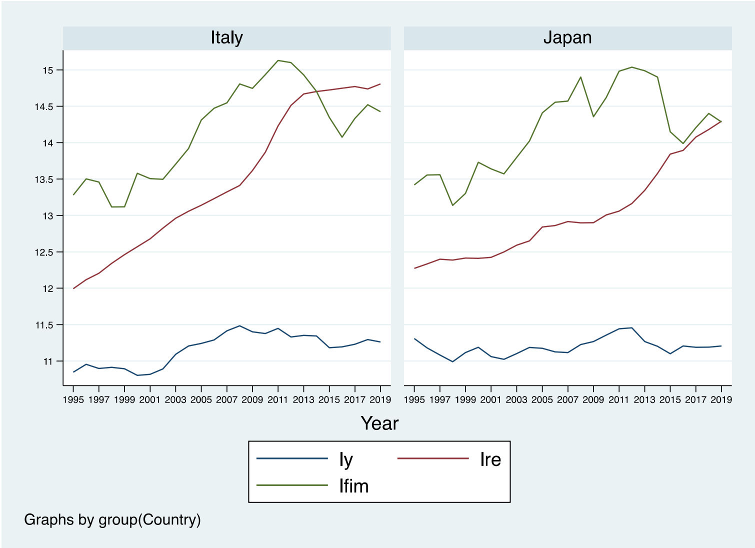


Figure 25 Economic Growth, Renewable Electricity, & Fossil-Fuels Imports over Time in Italy & Japan

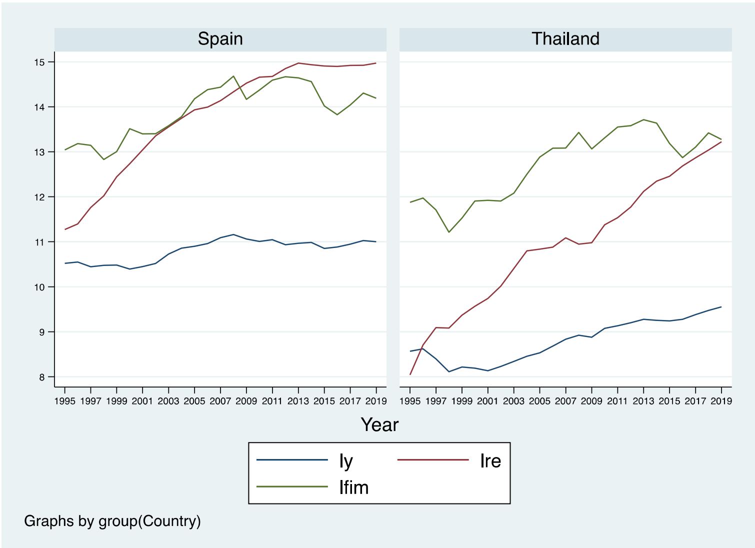


Figure 26 Economic Growth, Renewable Electricity, & Fossil-Fuels Imports over Time in Spain & Thailand

3.1.2 Descriptive Statistics

Table 4 and Table 5 cover descriptive statistics of exporters and importers data respectively.

Table 4 Descriptive statistics (Exporters)

Variable		*Mean*	*Std. dev.*	*Min*	*Max*	*Observations*	*Skewness*	*Kurtosis*
LY	overall	9.831282	1.155293	6.928131	11.76845	n = 150	-0.08536	2.044076
	between		1.131429	8.24241	11.17027	N = 6		
	within		.5106531	8.394072	10.8199	T = 25		
LK	overall	8.39288	1.167438	5.55887	10.49043	n = 150	-0.07658	2.240291
	between		1.105553	6.931773	9.817361	N = 6		
	within		.5809786	6.636626	9.484475	T = 25		
LRE	overall	11.26013	2.098298	7.218192	14.93125	n = 150	0.43726	2.276449
	between		2.157372	8.538611	13.69299	N = 6		

	within		.7058878	9.660351	13.08155	T = 25		
	overall		1.145256	11.30679	15.47179	n = 150		
LFEX	between	13.81408	1.048012	12.03454	14.61376	N = 6	0.49793	2.953303
	within		.6246542	11.92081	14.9399	T = 25		

Table 5 Descriptive statistics (Importers)

Variable		*Mean*	*Std. dev.*	*Min*	*Max*	*Observations*	*Skewness*	*Kurtosis*
	overall		1.457939	6.920378	11.50553	N = 8		
LY	between	10.06866	1.472981	7.759378	11.21758	n = 200	-0.89057	2.358643
	within		.4664591	8.60566	11.44883	T = 25		
	overall		1.279556	5.539546	10.08936	N = 8		
LK	between	8.697332	1.278114	6.543146	9.79954	n = 200	-0.9924	2.796266
	within		.4479988	7.396672	9.822484	T = 25		
	overall		1.916928	7.727256	15.44008	N = 8		
LRE	between	12.33628	1.498544	10.41842	13.87329	n = 200	-0.60827	1.999349
	within		1.303766	9.458285	15.67834	T = 25		
	overall		1.469771	8.315589	15.13079	N = 8		
LFIM	between	13.18514	1.297575	11.01105	14.16401	n = 200	-0.32659	2.601841
	within		.8243695	10.48969	14.90617	T = 25		

Observing descriptive statistics for both datasets, we can notice that the distribution of variables' values seems to configure a slightly high-pitched curve because all kurtosis values are above 1.9 and it illustrates the narrowness of data spread due to logarithmic effect. All data distributions are skewed, which makes sense for panel data that consists of time series of different economies.

The lowest LY recorded is 6.93 in 1998 for Indonesia (exporter) and 6.92 in 1995 for India (importer). The highest LY is 11.76 in 2013 for Australia (exporter), and 11.50 in 2012 for Japan. Viewing renewables consumption, we can observe a large difference between minimum and maximum values for both datasets. This difference may relate to the fact that renewables' costs dramatically become lower after the year 2007, therefore their adoption has risen steeply and reached levels much higher than 1990's levels. The change in fossil fuels exports is relatively small comparable to the other variables. While the fossil fuels imports change is slightly higher, this indicates that how the economic growth of net-importing countries is more related to more fossil fuels imports. The previous statistics give us an indication of the prospected relation between all variables and how they are positively connected to the economic growth in both groups of countries.

3.2 Methodology

The use of panel data has advantages that motivate researchers to adopt it. Firstly, the panel data analysis provides more information by combining the time series and cross-sectional dimensions. Secondly, this analysis not only reduces multi-collinearity among the independent variables but also increases the degrees of freedom, which in turn leads to more efficient estimated results. Thirdly, it controls the individual heterogeneity, and finally, it identifies the effects that cannot be detected in the time-series or cross-sectional analysis (Hasanov et al., 2017), (Rahman & Velayutham, 2020).

The datasets of this study have the following properties. Exporters' dataset has six panels (countries) (N = 6), the number of years is twenty-five (T = 25), the dataset is strongly balanced with 150 observations (n = 150). Importers' dataset has eight panels (N = 8), the number of years is twenty-five (T = 25), the dataset is strongly balanced with 200 observations (n = 200). In existing literature, we found that 27 studies included datasets with moderate-large T and small N where (N < T), 19 of these studies included a number of observations similar to this study (100 < n < 400). Implementing methodologies which have been tested on similar data structures gives our study more accuracy and precision to avoid spurious estimations.

Reviewing related studies and examining the characteristics of this research, a specific sequence of methods has been applied. The planned procedure has been verified to be statistically valid and implemented in six stages. Firstly, examining the presence of cross-sectional dependence between panels (countries) in each dataset (exporters & importers). Secondly, testing slope coefficients heterogeneity from panel to panel. Thirdly, applying three types of 2nd generation unit root tests to inspect the stationary status of each variable in both datasets. Fourthly, investigating the co-integration relations between variables using 2nd generation test followed by a robustness check using Kao test. Fifthly, estimating the two models using Fully Modified Least Squares technique (FMOLS). Finally, implementing Dumitrescu & Hurlin (2012) panel Granger non-causality[1] test to uncover the casual directions between the variables.

3.2.1 Cross-sectional Dependence and Slope Heterogeneity Tests

In the present interconnected and open world economy, panel causality analysis must take into consideration two important matters: cross-section dependence and slope heterogeneity.

Firstly, Countries have been experiencing a growing economic and financial integration with financial institutions. Given this integration, panel data literature has concluded that panel datasets are likely to exhibit considerable cross-sectional dependence, which may arise due to the presence of collective shocks, as well as unobserved components that basically form part of the error term. When cross-sectional dependence is found, the traditional panel unit root and

[1] We call it non-causality as literature did, because the null hypothesis is the non-causality between the variables

cointegration tests (1st generation) may result in large empirical size distortions and thus fail to evaluate clearly the integration and long-run relations between the variables (Chang et al., 2015). Secondly, concerning slope heterogeneity, when dealing with panel data methodologies, we should consider the variations across slopes (Betas) in each cross-section (country). Tests and methods that consider this issue should be applied to avoid biased estimations.

As suggested by Pesaran (2021) for small N sizes (N < 10), Breusch & Pagan (1980) Lagrange Multiplier (LM) test is suitable. Our datasets parameters are applicable (N = 6 , N = 8). The LM test used to assess the cross-sectional dependence. The LM test is shown in Eq. 6.

$$LM = T\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}^{2}{}_{ij}\right) \tag{6}$$

Where T is the panel's time dimension, N is the panel's cross-sectional dimension, $\hat{\rho}_{ij}$ is the sample estimate of the pairwise correlation of the residuals.

Pesaran (2004) test (LM_{CD}) and (Pesaran et al., 2008) bias-adjusted test (LM_{adj}) are also widely used methods for testing cross-sectional dependence in panel datasets. We used these tests to check robustness of (LM) test. The null hypothesis (H_0) of each test is that the panels are cross-sectionally independent. Rejecting the null hypothesis means that the alternative hypothesis is valid (H_a); the presence of cross-section dependence among panels.

The second issue considered here is to test whether or not the slope coefficients are homogenous. The homogeneity assumption for the parameters is not able to capture heterogeneity due to country specific characteristics. Swamy (1970) test is applicable to our datasets. Pesaran & Yamagata (2008) suggested that seemingly unrelated regression equation (SURE) framework developed by Zellner (1962) which is used by Swamy test is suitable for small N and large T. However, we used a standardized more efficient method developed by Pesaran & Yamagata (2008). The test has two indicators, delta ($\widetilde{\Delta}$) and bias-adjusted to small sample properties namely delta adjusted ($\widetilde{\Delta}_{adj}$). The null hypothesis of the test indicates that slope coefficients are homogenous ($\beta_0 = \beta_1 = \beta_2 = \cdots \beta_i$) where ($i$) is the cross-sectional unit (country). Rejecting the null hypothesis suggests that the slope coefficients are heterogenous ($\beta_0 \neq \beta_1 \neq \beta_2 \neq \cdots \beta_i$).

3.2.2 Panel Unit Root Tests

In order to apply co-integration tests and examine the long run relationship between the variables, we have to investigate the presence of unit roots in each variable. Implementing cointegration methods requires the stationary of variables within the same order (Pesaran, 2007). The possible presence of cross-sectional dependence (CD) in panel data urged researchers to develop a 2nd generation of tests that take into account (CD). 1st generation unit root tests assume that cross sections within panels are independent (Burdisso & Sangiácomo, 2016).

We used Pesaran (2007) CIPS test which is based on the IPS test developed by Im et al. (2003). The transformed test takes in consideration the presence of cross-section dependence and it is suitable for fixed small N and moderate T dimensions. Another highly reliable test proposed by Breitung & Das (2005) which accounts also for (CD) has been used as a robustness check to CIPS. Optimal lag selection for each variable series in both tests has been facilitated by Akaike Information Criterion (AIC). Selecting the suitable lag for unit root tests reduces incorrect specifications bias (Akaike et al., 1998). CIPS test is expressed in Eq. (7)

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (7)$$

Where N is the total number of cross sections, i is the order of each cross section, and CADF is the t-statistics that are obtained from each cross-section regression.

Considering group-wise heteroscedasticity, we used Herwartz & Siedenburg (2008) test which has been developed taking into account overcoming this issue. It is also used as an additional robustness check for previous tests. For testing panel heteroscedasticity, Following Greene (2000), we implemented Modified Wald statistic in a fixed effect model.

The null hypothesis of all tests is the presence of unit root, rejecting the null hypothesis confirms that the variable is stationary. Taking the first or second difference might be necessary to construct the variables' series stationary of order one I(1) or order two I(2).

The execution of co-integration tests can be carried out de-biased if the variables are stationary at the same level, e.g., 1st difference or 2nd difference.

3.2.3 Co-integration relationship Tests

The notion of co-integration was first presented by Granger (1981) and developed further by Engle & Granger (1987), Phillips & Ouliaris (1990) and Johansen (1991). The fundamental idea of co-integration is that if two or more time series variables are individually integrated of order n, then there is a possibility of at least one linear combination of them to be integrated of a lower order such that $\tilde{n} < n$. Such a relationship between the variables infers cointegration. Cointegrated variables reveal strong steady-state relationship over the long term, having mutual trends and co-movements. The theory of cointegration affirms that there are linear combinations of integrated variables that cancel out common stochastic trends. This occurrence gives rise to equilibrium relationships among integrated variables, which means that in the long run these variables show co-movement with each other.

In this study, two co-integration tests have been used, the first test is based on Pedroni (1999, 2004) papers. The test includes seven subtests namely, v-panel, rho-panel, t-panel, adf-panel, rho-group, t-group, and adf-group. The tests consider dynamic panels in which both the short-run dynamics and the long-run slope coefficients are permitted to be heterogeneous across individual members of the panel. The tests also allow for individual heterogeneous fixed effects and trend terms. Eq. (8) displays the regression used to run the tests.

$$y_{it} = \alpha_i + \delta_i t + \sum_{j=1}^{M} \beta_{ij} x_{ji,t} + \epsilon_{it} \tag{8}$$

For a time series panel of observables y_{it} and x_{it} for members i = 1,….N over time periods t = 1,….T. Where x_{it} is an M-dimensional column vector for each member i and β_{ij} is an M-dimensional row vector for each member i. The variables y_{it} and x_{it} are assumed to be integrated of order one, denoted I(1) for each member i of the panel, and under the null of no cointegration the residual ϵ_{it} will also be I(1). The parameters α_i and δ_i allow for the possibility of member specific fixed effects and deterministic trends, respectively. The slope coefficients β_{ij} are also permitted to vary by individual, so that in general the cointegrating vectors may be heterogeneous across members of the panel.

The second test is (Kao, 1999) co-integration test which is commonly used in literature as a supporting test for Pedroni tests' indecisive results (Rahman & Velayutham, 2020), (Maji et al., 2019), (Rasoulinezhad & Saboori, 2018). The two tests assess two hypotheses, the null hypothesis of no co-integration between variables, and the alternative hypothesis which suggests that there is a long run relationship between variables.

3.2.4 Estimation Method and Causality Test

Most of notable studies in the field have applied Fully Modified Least Squares (FMOLS). The method was developed by Pedroni (2000) as an estimation method for panel models. It is appropriate to implement this estimation if co-integration relationships are verified. FMOLS is widely used due to its ability to correct endogeneity bias, serial correlation, and simultaneous bias (Hamit-Haggar, 2012), (Ozcan, 2013), (Kasman & Duman, 2015). The regression equation of FMOLS is given in Eq. (9)

$$y_{it} = \alpha_i + \gamma_i t + \beta_i x_{it} + \epsilon_{it} \tag{9}$$

Where y_{it} is the dependent variable, α_i is the intercept, β_i is the slope coefficient, x_{it} is the explanatory variable, γ_i the coefficient of trend term, and ϵ_{it} is the error term.

Even though the coefficients obtained from the FMOLS specify the long-run relationship between variables, they are incapable to convey information about the causality direction between variables. The study uses a Granger non-causality test proposed by Dumitrescu & Hurlin (2012) to reveal causality relationships. The test can be performed when the time dimension (T) is higher or lower than the cross-section dimension (N) {(T > N) or (T < N)}. This test is based on Wald statistics and Monte-Carlo Simulations, which are statistically valid when the sample is small, and there exists cross-sectional dependence (Dogan & Seker, 2016), (Koçak & Şarkgüneşi, 2017). The test's null hypothesis suggests that the independent variable does not Granger-cause the dependent variable. Rejecting the null hypothesis implies that the independent variable does Granger-cause the dependent variable. We might use bootstrap procedure within the test if the panels are strongly cross-sectional dependent (Lopez & Weber, 2017).

3.3 Empirical Results

In this section, we will perform the previous tests and analyze the obtained results to reveal the relationships between the variables. We will be able to understand the connections between variables in each dataset so that we can present useful and factual policy recommendations. All statistical methods were applied using STATA 17.0 with 20-Oct-21 updates.

3.3.1 Cross-section Dependence and Slope Homogeneity

The first step in the econometrics analysis is to perform the cross-sectional dependence tests and slope homogeneity (SH) tests. Table 6 report the results of the proposed CD and SH tests for Exporters and Importers respectively.

Table 6 CD & SH results

Country Type	*Test*	*Test-Statistic*	*p-value*
Exporters	LM	15.79	0.3962
	LM adj	-.4597	0.6457
	LM CD	1.021	0.3071
	$\widetilde{\Delta}$	6.259	0.0000***
	$\widetilde{\Delta}_{adj}$	6.998	0.0000***
Importers	LM	90.11	0.0000***
	LM adj	19.1	0.0000***
	LM CD	3.481	0.0005***
	$\widetilde{\Delta}$	11.140	0.0000***
	$\widetilde{\Delta}_{adj}$	12.455	0.0000***

Note * reject H_0 at 10% significance level.
** reject H_0 at 5% significance level.
*** reject H_0 at 1% significance level.

Table 6 clearly state that exporters series are cross-sectionally independent. P-values of the three tests accept the null hypothesis of no cross-section dependence among panels. It means that shocks in the global market may not spill over evenly on the selected exporters' economies. On the contrary, Importers' part of Table 6 reports the presence of cross-section dependence in importers' economies. The eight countries included in this study seem to be affected mutually by global shocks, as a result, their economies respond relatedly. All p-values reject the null hypothesis of cross-sectional independence within the 1% significance level. The existence of CD in one dataset and its absence in the other drives the study to adopt methodologies that accounts for CD; Using unit root tests and cointegration tests that consider CD in both models is applicable and statistically valid.

From Table 6 also, we can observe that p-values of $\widetilde{\Delta}$ and $\widetilde{\Delta}_{adj}$ strongly reject the null hypothesis of homogenous slope coefficients in both groups. Thus, slope coefficients in both datasets are heterogenous and the issue will be considered in following tests.

3.3.2 Unit Root Tests

The application of 2nd generation unit root tests should be implemented in importers dataset due to the presence of CD. Despite the fact that exporter's dataset doesn't have CD, 2nd generation unit root tests are applicable and statistically valid (Pesaran, 2007). We employed three unit-root tests on both datasets, namely, CIPS, Breitung, and Herwartz tests. The options of running the tests with trend and intercept are available, but most of literature in this field have used the first difference as a second option to overcome the different outcomes when running intercept or trend with the regression. Before running the tests, we applied panel heteroscedasticity test for both models to confirm the requisite for Herwartz unit root test, and we used AIC to identify the optimal lags for CIPS and Breitung tests. Table 7 reports the existience of panel heterescedastcity, and reject the null hypothesis of homoscedasticty. As a result it affirms the necessity to use Herwartz test as a supporting unit root test. Unit root tests' results are reported in Table 8 for exporters and importers variables respectively.

Table 7 Modified Wald test for groupwise heteroskedasticity

Indicator / Dataset	***Exporters***	***Importers***
chi2 (8)	640.15	178.02
Prob>chi2	0.0000	0.0000

Table 8 Unit root tests results

Variable/Test	***CIPS***	***Breitung***	***Herwartz***	***CIPS (1st diff.)***	***Breitung (1st diff.)***	***Herwartz (1st diff.)***
Exporters						
LY	-2.149	1.0107 (0.8439)	1.0551 (0.8543)	-4.157***	-5.9099 (0.0000)***	-1.8253 (0.0351)**
LK	-2.672***	0.8024 (0.7888)	-0.0583 (0.4767)	-3.996***	-4.1879 (0.0000)***	-1.4337 (0.0762)*
LRE	-1.084	4.9551 (1.0000)	1.6871 (0.9542)	-3.528***	-5.3505 (0.0000)***	-2.0565 (0.0199)**
LFEX	-2.478**	0.3869 (0.4729)	-0.3355 (0.3686)	-3.958***	-4.7784 (0.0000)***	-2.3246 (0.0100)***
Importers						
LY	-3.029***	3.9345 (1.0000)	0.4698 (0.6808)	-3.962***	-3.5216 (0.0000)***	-1.8321 (0.0335)**
LK	-1.983	3.0731 (0.9989)	0.1554 (0.5618)	-3.697***	-4.2581 (0.0000)***	-2.2158 (0.01347)**
LRE	-1.988	8.2971 (1.0000)	3.3903 (0.9997)	-3.600***	-3.1853 (0.0005)***	-2.9739 (0.00124)***
LFIM	-1.552	0.7794 (0.7821)	0.3045 (0.6196)	-5.406***	-4.4739 (0.0000)***	-2.7592 (0.00197)***

Note: For CIPS test, critical values are -2.25 (5% level) and -2.51 (1% level).
For the other tests p-values are in parentheses.
* reject H_0 at 10% significance level.
** reject H_0 at 5% significance level.
*** reject H_0 at 1% significance level.

Reviewing Table 8, exporters' CIPS test reports that LY, LRE, and LFEX have unit roots, while LK is stationary. All variables are stationary at first difference, rejecting the null hypothesis of unit root existence. Breitung test confirms the existence of unit roots in all variables at levels, while rejecting the null hypothesis at first difference. Herwartz test also confirms that there are unit roots in all variables and states that they are all stationary at first difference. Taking collective observation for all tests, we can safely conclude that all exporters' variables are stationary at first difference and integrated of order one I(1).

Importers' dataset appears to be the same, CIPS test is stationary at levels only in LY, while other variables have unit roots. At first difference, all variables are stationary. Other tests confirm that all variables have unit roots at levels and stationery at first difference. Given all results, we can assuredly conclude that variables are stationary at first difference and integrated in order one I(1).

3.3.3 Co-integration Relationship Tests

After having confirmed that all series are integrated in the same order, the next step in our analysis is to examine the long run association between the selected variables. Pedroni & Kao tests have been conducted and reported in Table 9. The option of lag-select is automatically selected by Stata 17.0. The option of trend is not included following the literature in this procedure (Apergis & Payne, 2011a), (Ucan et al., 2014b), (Koçak & Şarkgüneşi, 2017), (Alvarado et al., 2019), and (Maji et al., 2019).

Table 9 Co-integration tests results

Co-integration Tests	*Exporters*		*Importers*	
Pedroni Tests	***Stat.***	***P-value***	***Stat.***	***P-value***
Panel-v Statistic	-0.662	0.74601	0.8006	0.21168
Panel-rho Statistic	0.6512	0.25745	1.839	0.03025**
Panel-t PP Statistic	1.334	0.091102*	1.877	0.0302**
Panel-adf Statistic	2.266	0.0039**	1.649	0.04957**
Group-rho Statistic	1.526	0.033504**	2.805	0.00251***
Group-t PP Statistic	-0.9668	0.83317	1.668	0.0476**
Group-adf Statistic	2.999	0.0013***	0.4997	0.30864
Kao Tests	***Stat.***	***P-value***	***Stat.***	***P-value***
Modified Dickey–Fuller t	-2.6722	0.0038***	-4.1845	0.0000***
Dickey–Fuller t	-2.2466	0.00959***	-3.0727	0.0011***
Augmented Dickey–Fuller t	-1.9390	0.0263**	-3.1708	0.0008***
Unadjusted modified Dickey–Fuller t	-2.6700	0.0038***	-4.0496	0.0000***
Unadjusted Dickey–Fuller t	-2.1459	0.0159**	-3.0355	0.0012***

Note: * reject H_0 at 10% significance level.
** reject H_0 at 5% significance level.
*** reject H_0 at 1% significance level.

Viewing Table 9, seven subtests of Pedroni test have been reported, four of them reject the null of no co-integration among variables. Kao results reject the null of no co-integration for all out the sub-tests reported. A total of twelve tests have been listed, nine of them confirm that there is a co-integration relationship between the series of selected variables at least at the 10% level of significance, six of them at the 1% level. Despite the insignificance of three tests, following literature, we conclude that there is a long run association across exporters' variables.

Importers' dataset exhibits stronger evidence of long run co-integration between variables. Ten tests rejected the null hypothesis at the 5% level of significance. Moreover, six tests rejected the null of no co-integration at the 1% level of significance. A long-run relationship between importers' variables is confirmed.

3.3.4 Model Estimation & Causality Test

In this section we will finalize econometric procedure to find the anticipated results and reveal the long run coefficients of studied variables. We will also uncover the directions of causality links between each pair of variables.

3.3.4.1 FMOLS Estimation

Given that variables are integrated of order one I(1) in the long run, we employed FMOLS to estimate the long run coefficients of the variables. Table 10 reports the results of FMOLS for exporters and importers datasets respectively. Variables' conversion to logarithmic form allows us to explain coefficients as elasticities.

Table 10 Panel FMOLS estimation results (LY as the dependent variable)

Independent Variables	***Coefficients***	***t-statistics***	***p-values***
Exporters			
LK	0.77	139.90	0.0000***
LRE	0.08	19.07	0.0000***
LFEX	0.07	19.31	0.0000***
Importers			
LK	0.62	93.16	0.0000***
LRE	0.10	49.99	0.0000***
LFIM	0.04	19.41	0.0000***

Note: * statistically significant at the 10% level.
** statistically significant at the 5% level.
*** statistically significant at the 1% level.

Inspecting results of exporters' model, we found that per labor Net Gross Capital Formation, per labor Renewable Electricity Consumption, and per labor Fossil Fuels Exports have positive long run effects on economic growth. The coefficients are statistically significant at the 1% level. Observing importers' results, we found similar outcomes, all variables have positive long run effects on economic growth.

The estimation of exporters model reveals that a 1% increase in gross capital formation has led to a 0.77% increase in GDP per capita. A 1% increase in renewable electricity consumption and fossil fuels imports has driven the GDP per capita to increase by 0.08% and 0.07% respectively. Importers' model estimation uncovers that a 1% increase in gross capital formation is associated with a 0.62% increase in GDP per labor. Regarding renewable electricity consumption, a 1% rise in RE positively changes GDP per labor by 0.10%. Each 1% increase of Fossil fuels' imports drove GDP per labor by a 0.04% higher.

Given the estimated coefficients, there is a highly correlated long run relationship between capital formation and economic growth in both models. The change in capital formation is accompanied with over 60% of the change occurs in GDP. Renewables appear to impact or be impacted by economic growth in importers slightly higher than exporters. It confirms our observations; Exporters tend to use their reserves rather than investing in renewables, thus we found low RE coefficient within GDP model. On the other hand, importers are more motivated to find alternatives and reduce dependence on fossil fuels imports. Therefore, their long run investment in renewables led to slightly more RE, and since energy in general affect economic growth, the more the share of RE the more it appears to interact with the economy. Considering fossil fuels trade in both models, exports seem to affect economic growth in net-exporting economies two times the impact of imports in net-importing economies. Despite that, both coefficients in both models are relatively small.

3.3.4.2 Panel Causality Test

The application of Dumitrescu & Hurlin (2012) panel non-causality test is implemented to find the casual relationships between variables. previous tests and methods were necessary to verify the relational correlation among variables and assure the validity of using the causality test. We should note that we applied the test within a bootstrap procedure with 750 replications for importers dataset due to the existence of strong CD. Table 11 reports results of casual links across variables pairs. We should also note that the test has been conducted on variables pairs that serve the research purpose rather than examining all possible combinations. We selected $\tilde{\boldsymbol{Z}}$ as the indicator-statistic which fits our datasets conditions of fixed T > 5 + 3K where K is the lag order (Lopez & Weber, 2017).

Table 11 Results of Panel Causality Test

Direction of Causality	*Lag [a]*	*$\tilde{Z}$ Stat.*	*P-value*
Exporters			
LK → LY	6	3.6830	0.0002***
LRE → LY	1	3.9528	0.0001***
LFEX → LY	2	3.2123	0.0013***
LY → LK	1	0.8695	0.3846

LY → *LRE*	6	6.3323	0.0000***
LY → *LFEX*	4	3.8531	0.0001***
LRE → LFEX	6	1.2475	0.2122
LFEX → LRE	4	-1.1168	0.2641
Importers			
LK → *LY*	1	13.9172	0.0000***
LRE → *LY*	1	7.1133	0.0000***
LFIM → *LY*	6	2.9253	0.0450**
LY → *LK*	1	1.9896	0.0700*
LY → *LRE*	1	12.9910	0.0000***
LY → *LFIM*	1	1.5306	0.1259
LRE → LFIM	2	-0.4019	0.6878
LFIM → LRE	1	9.2568	0.0000***

Note: * reject H_0 at 10% significance level.
** reject H_0 at 5% significance level.
*** reject H_0 at 1% significance level.
a Optimal lag has been selected using Bayes Information Criterion (BIC).

Causality test uncovers five significant casual links among **exporters** variables. Capital formation, fossil fuels exports and renewable electricity consumption do Granger-cause economic growth at the 1% level of significance. Whilst economic growth does Granger-cause renewable energy and fossil-fuels exports at the 1% level of significance. Results from **importers** reveal six significant casual links. Capital formation, renewable energy, and fossil fuels imports do Granger-cause economic growth at the 1% and 5% levels of significance. Also, economic growth does Granger-cause capital formation and renewable electricity consumption at the 10% and 1% levels respectively. Fossil fuels imports do Granger-cause renewables consumption at the 1% significance level.

In exporting countries, renewables appear to have a unidirectional casual effect on economic growth supporting the **feedback hypothesis**. it implies that renewables promoting policies can be rewarding to the economy and economic growth promotion will lead to more renewables consumption. Fossil fuels exports have a bi-directional causal relationship with economic growth. Fossil fuels exports affect economic growth in fuels-exporting economies because a huge part of income comes from fuels exports. In addition, economic growth seems to cause more exports too, encouraging the industry activities to continue.

Results from importing countries exhibit almost similar behavior, economic growth has a bi-directional causal impact with renewables consumption, supporting the **feedback hypothesis**. It infers that the economic growth is leading to more renewables adoption and vice versa in importing countries. There is also a bi-directional casual effect between capital formation and economic growth. Given that six out the eight importing countries are industrial highly developed economies, efficient accumulation of capital appears to be a good instrument to boost the economy. The causal link found from fossil fuels imports to renewables consumption may represent the state of urgency that importing countries identify to replace fuels imports with sustainable alternatives. The unidirectional impact of imports on economic growth is significant given that these imports are used to produce valued goods and services and therefore increase economic growth.

4 Conclusion

4.1 Discussion

Governments around the globe recognize the importance of energy stability within their countries. Therefore, they take the necessary actions to ensure the availability of its resources. However, pollution, global warming, political conflicts and economic recessions might disturb the quality and quantity of the energy provided. These factors also impact living standards and environment ecosystems. Given that 80% of world's energy comes from fossil-fuels and that they are the major CO_2-emitting source globally; Fossil-fuels trade largely affects the world economies. Countries with high dependence on these fuels are under increasing pressure caused by climate-change international commitments, price shocks, and supply chain disruptions. Shifting to sustainable renewable energy sources sounds the best path to take. However, multiple barriers could prevent a suitable execution; Ignoring these factors and take impulsive decisions would probably produce undesirable results.

The study provides a sort of comprehension of the interrelations between previous factors. The study used panel data methodologies and analysis to uncover the relationship between renewable energy consumption and economic growth in fossil-fuels-dependent economies over the period 1995-2019. A set of six exporting countries and eight importing countries were included. The study applied multiple consecutive tests to ensure that each method is validated. Cross-section dependence test, slope heterogeneity test, panel heteroscedasticity test, unit root tests, and co-integration tests were implemented to select the suitable estimation technique and causality test.

The findings from **exporters** show that 1% increase in LRE drives the economic growth by 0.08%. Significant elasticities of LK and LFEX with respect to LY are 0.77 and 0.07 respectively. The significance of capital factor illustrates the huge impact of capital formation on economic growth, and how the accumulation capital can lead to a release of liquidity in the future and might also open up new economic activities. These effects are commonly visible in macroeconomic analysis and the capital formation is sought to be one of the major factors that affects the economic growth. In this model, the renewable energy variable comes second in terms of impact magnitude. The 0.08% change in economic growth seems modest, but taking in consideration that renewables are also still not fully adopted raises a flag. We can conclude that even the small share of renewables is affecting the economy in a significant degree. Fossil fuels exports' variable is a primary characteristic of the model and the magnitude of change that apply on the economy is significant.

Regarding causality links, LFEX have a bi-directional causality with LY. And LRE has also a bidirectional causal link with LY supporting the ***feedback hypothesis***. These results confirm the FMOLS model results with more elaboration on the type of the relationship between the variables. Economic growth seems to be benefited from fossil fuels exports and the more the growth the more these countries are exporting fuels. Renewables and economic growth also have the same relationship with a little higher magnitude of impact.

The findings from **importers** show that 1% rise in LRE increases LY by 0.1%. Significant elasticities of LK and LFIM with respect to LY are 0.62 and 0.04 respectively. Capital formation coefficient in this model asserts the same statement from exporters model that capital accumulation has a huge share in the economic growth. Renewables seems to have a slightly greater impact on the economy for importing countries than exporting countries. Fossil fuels imports have less impact on the economy in importers than the impact of fuels exports in exporters, but it is still statistically significant.

Regarding causality connections, LK and LY have a bi-directional causality relationship. LFIM has a unidirectional causal link to LRE and LY. Economic growth (LY) also has a bidirectional casual impact on LRE supporting the ***feedback hypothesis***. The impact of renewables appears to be the same in both groups of countries supporting the interchanging relationship with economic growth. Regarding LK in importers, the capital formation affects the economy in both directions. It means the interaction of the economic activities with capital formation is from LK to LY and vice versa. While the impact of fossil fuels imports is with one direction towards economic growth, there is also another impact from imports on the renewables.

4.2 Policy Recommendations

Similar studies usually aim to suggest policies that supposedly will improve the economic performance. For most countries, the appropriate policy to adopt needs continuous feedback to adjust accordingly. Doing research about the impact of RE on GDP should be frequent and accumulative to be beneficial and definitive. Our results indicate specific policy recommendations for the studied groups.

Exporters appear to benefit from the relatively slow increase of renewables and the economic growth has also an impact on this increase. The economic growth that is driven by renewables should be exploited and increasingly amplified because it is not going to harm the replacement of fossil fuels consumption. The long-run future of fossil-fuels is ambiguous; Therefore, part of the economic gain from fuels exports is recommended to be dedicated for renewables investments to protect exporting countries from any fossil fuels progressive decline. Proportionate and continuous investments in renewables can accumulate to form a large percentage of total electricity consumption. This will increase available fossil-fuels reserves which are usually used to generate electric power in traditional power plants, and so it would strengthen trade position of exporters. Global fossil-fuels consumption is not going to decline in the medium run, but market stability is questionable. Diversification of economic activities is a must for exporters, price shocks could last longer than predicted and this will bring rescissions which can be mitigated by exploiting exports surplus in different economic activities.

Importing countries appear to take better track with increasing renewables shares. Economic growth is the driver for this increase but the results also showed that renewables have a positive impact on the economy. This interchanging relationship indicates the rising importance of renewables on all economic activities. Taking advantage of the acceptable economic growth, it is recommended to increase renewables investments to reach sustainability goals and achieve energy security and independence in the long run. More investments in renewables will lead to more energy security and will not harm the economy as feared by fossil fuels advocates. Concerning fossil fuels imports, the imports coefficient is small and but the causality is significant. Therefore, this asserts the previous recommendation that a robust switch to renewables will not harm the economy, and the national measures that aim to replace fossil fuels are highly recommended.

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