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Article

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The Link between Economic Growth and Sustainable Energy in G7-Countries and E7-Countries: Evidence from a Dynamic Panel Threshold Model

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ABSTRACT

The available literature on sustainable energy use and economic growth nexus yields conflicting conclusions, as the effect can be positive, negative, or insignificant. This research explores the causal link between sustainable energy use and economic growth in G7-countries (Japan, Canada, Germany, Italy, France, United Kingdom, and United States) and E7-countries (Russia, Brazil, Indonesia, China, Mexico, India, and Turkey) countries from 1990 to 2019. We discover that sustainable energy use and economic growth are proportional. Our results show that sustainable energy use positively affects economic growth if E7-countries exceed a specific threshold. It is detrimental to economic growth for the E7 countries' sustainable energy use to fall below a certain threshold. The use of sustainable energy has no significant impact on economic growth, although it does have a positive and noticeable impact in the G7 countries. In order for the countries of the G7 to see positive economic growth as a result of their investment in renewable energy, it is necessary for those nations to surpass a certain threshold in terms of their use of sustainable energy.

Keywords: Economic Growth, Sustainable Energy, Threshold Effects, G7 Countries, E7 Countries
JEL Classifications: C24, O13, Q43

1. INTRODUCTION

Over the past few years, sustainable energy sources have become increasingly important in the world's energy use spectrum as a result of climate change, variable energy prices, and favorable government policies. Increases in GHG emissions are a result of the provision of energy services, and increasing the use of sustainable energy not only reduces CO_2 emissions but also has the potential to mitigate climate change (Shafiei and Salim, 2014; Balsalobre-Lorente et al., 2018; Inglesi-Lotz and Dogan, 2018; Belaïd and Zrelli, 2019) The relationship between sustainable energy use and economic growth has been extensively researched in light of the rise in the utilization of sustainable energy sources. In a growing body of research, researchers have found no link between energy use and economic growth, a finding known as the "neutrality hypothesis" (Menegaki 2011; Omri et al., 2015; Bulut and Muratoglu, 2018). Another body of literature, on the other hand, found that using sustainable energy boosted economic growth (Ozturk and Bilgili, 2015; Inglesi-Lotz, 2016; Bhattacharya et al., 2016). The third body of research shows that rising use of sustainable energy has resulted in negative economic growth as a result of high investment costs (Ocal and Aslan, 2013; Bhattacharya et al., 2016) As a result, there appears to be no consensus in the research regarding the impact of sustainable energy use on economic growth. Using evidence from the current literature, we hope to show why researchers have come up with such a confusing and contradictory set of findings. There may be a difference in economic growth depending on how much sustainable energy is consumed, which is why using a threshold model like the panel threshold model can help explain why the results differ when different countries are taken into account. If a country's sustainable energy use falls below or beyond a certain threshold, the panel threshold model can be used to examine the relationship between sustainable energy use and economic growth. There are several reasons why we believe that the use of sustainable energy will have an impact on economic growth, which we describe in more depth below.

According to the research, sustainable energy sources have a lower storage capacity than fossil-based fuels, which may lead to energy supply issues during peak demand periods (Heal, 2009; Apergis and Payne, 2010). It is also important to note that moving from fossil fuel sources to technology-based sustainable energy demands considerable upfront investments, which may have a detrimental impact on economic growth (Marques and Fuinhas, 2012; Ocal and Aslan, 2013). Furthermore, (Marques and Fuinhas, 2012) believe that governmental policies that may boost the final cost of energy, providing regulators include these expenses in the final price of power, will provide the costs of developing sustainable energy sources. According to (Astariz and Iglesias, 2015), the most cost-effective method was pulverized fuel, in which the production cost of an energy unit from fossil fuel sources was lower than that of sustainable energy sources. Due to the factors described above, increasing sustainable energy sources could have a detrimental impact on economic growth. Even though the initial investment expenditures of sustainable energy sources are high compared to fossil fuel sources, solar and wind technologies have declined in cost over the previous few years, leading to lower sustainable energy generation costs. (Rubin et al., 2015) conducted an analysis of the actual education rates that were reported for a wide variety of technologies used to generate electric power. Their findings indicate that educational rates at fossil fuel power plants were lower than those at sustainable energy technologies. As shown by (Schilling and Esmundo, 2009), the generation of power per kwh has increased as R & D expenditure on sustainable energy technology has decreased, indicating that the costs of sustainable energy have decreased as investment has decreased. Sustainable energy costs are expected to be cheaper in countries that use more of them.

This means that nations that utilize less sustainable energy may have greater costs for using sustainable energy relative to fossil fuels, which may not have a substantial impact on economic growth (or perhaps a negative impact) for these countries. Usage of sustainable energy can have a positive effect on economic growth, especially when it is used in greater quantities than in countries with lower sustainable energy usage. As a threshold variable, we look at the impact of sustainable energy use on economic growth above and below the threshold of sustainable energy use. There are numerous ways this study contributes to current understanding. According to a review of the literature, a number of current research uses a variety of panel estimating methodologies to explore the causal link between sustainable energy usage and economic growth. To the best of our knowledge, only a few studies have studied the potential non-linear link between sustainable energy usage and economic growth. Researchers used panel sample splitting to examine if the impact of sustainable energy use on economic growth differs at a threshold level and at lower levels. When it comes to unit root and cointegration testing, most prior research has assumed cross-sectional independence. The assumption of cross-sectional independence is commonly violated by macro-level data, resulting in poor power and size distortions in tests that presume this assumption (Pesaran, 2014). Panel data approaches that take cross-sectional dependence into consideration are used in this study. Previous studies have shown that the relationship between using sustainable energy and economic growth changes depending on the set of countries used. We also look into whether the results of a threshold model for the countries like the G7-countries and E7-countries.

The remaining parts of the paper are structured as described below. In the second section, a literature review is presented, which investigates the connection between the use of sustainable energy and the expansion of the economy. In the third portion, the discussion on data and theoretical threshold model is developed, and in the fourth section, the empirical findings and robustness analysis are presented, and the paper is brought to a close in the section 5, which also contains some policy recommendations.

2. LITERATURE REVIEW

According to the past studies, (Mozumder and Marathe, 2007; Apergis and Payne, 2010; Magazzino, 2011) are the four most frequent hypotheses about the relationship between energy use and economic growth, each of which is critical for energy policy. There is an initial correlation between energy use and economic growth, which suggests that energy use limits may inhibit growth is called growth hypothesis, while increases in energy use may be a positive factor for economic expansion. In the second place, the conservation hypothesis suggests that economic growth is unidirectionally causally linked to energy use, which means that energy use conservation policies may have little or no impact on economic growth in countries with a lower reliance on energy, whereas economic growth drives up energy use. Energy use and economic growth are linked by a feedback hypothesis, which states that the both are connected by a bidirectional causal relationship. There is no causal relationship between energy use and economic growth, hence neither inclusive nor exclusive energy use policies affect economic growth, according to the neutrality hypothesis. It is not uncommon for researchers in the energy field to investigate the link between energy usage and economic growth. According to these studies, the causal relationship between GDP and energy use is rather inconsistent in terms of the four hypotheses. There is a meta-study by (Menegaki, 2014; Iyke, 2015) that provides an overview of the many articles and their results for the energy-growth nexus.

Panel co-integration, Granger causality, and long-run structural estimates are also used by (Narayan and Smyth, 2008) to evaluate the causal relationship between energy use and real GDP for G-7 countries between 1972 and 2002. According to the findings, economic growth and energy use have a long-term, unidirectional causal relationship. Several other research, such as (Lee and Chang, 2005) for emerging nations, (Glasure and Lee, 1998) for Singapore, and (Masih and Masih, 1996) for Asian countries, found the same results using various econometric methodologies. There are a variety of approaches used to investigate the link between sustainable energy use and economic growth in different countries and time periods such as (Apergis and Payne, 2010; Apergis and Danuletiu, 2014; Ozturk and Bilgili, 2015; Chang et al., 2015; Inglesi-Lotz, 2016; Bhattacharya et al., 2016; Kahia et al., 2017; Bulut and Muratoglu, 2018; Saqib 2021, 2022a; Sharif et al., 2022). Panel data methodologies such as panel cointegration tests, Granger causality, dynamic or vector error correction methods, and fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) are commonly used to examine the relationship between sustainable energy use and economic growth. The use of the linear autoregressive distributed lag (ARDL) approach to cointegration developed by (Pesaran et al., 2001) and the non-linear ARDL developed by (Shin et al., 2014) has also been a popular methodology in this relationship see, for example: (Tugcu et al., 2012; Tugcu and Topcu, 2018) for the use of linear and non-linear ARDL methods in examining the relationship between sustainable energy and economic growth. Lastly, the generalized techniques of moments, also known as GMM, is yet another panel methodology that has been used. GMM is able to address any endogeneity issues (Omri et al., 2015; Bhattacharya et al., 2017).

(Rafindadi and Ozturk, 2017) use monthly data from 1971 to 2013 to examine the impact of sustainable energy on economic growth in Germany. Increasing energy use by 1% raises real GDP by 0.22%, according to the findings of the research. In EU economies that satisfy energy targets set forth in the Paris Agreement and the Kyoto Protocol, sustainable energy use is increasing, which may lead to a reduction in carbon footprints. In a similar vein, (Emir and Bekun, 2018) found that sustainable energy use in Romania between 1990 and 2014 was more responsible than any other element for guiding the ecological environment. When it comes to carbon footprints, however, sustainable energy usage has the opposite impact (Nathaniel and Iheonu, 2019). fossil fuel sources usage in African economies contributed significantly to environmental degradation between 1990 and 2014, according to the AMG methodology. (Nasreen et al., 2017) evaluated the relationship between fossil fuel sources use and carbon footprints in South Asian economies from 1980 to 2012 and found that fossil fuel sources use increases carbon footprints, which in turn worsens the environment's condition. Including sustainable energy goals in a wider strategy for long-term energy market management, energy conservation, and technological improvement will aid in the adoption of sustainable energy (Saqib et al., 2022). Although economic growth has been strong in the developed countries (Saqib, 2022b) and increased investments in sustainable energy is needed to expand the use of solar and wind power and enhance appliance energy efficiency.

(Saqib, 2018) explores the relationship between greenhouse gas (GHG) emissions, energy use, and economic growth in GCC countries from 1996-2017. This study shows a bidirectional causal link between energy use and economic growth. The results suggest unidirectional causality from energy use to GHG emissions without feedback effects, and a bidirectional causal relationship between economic growth and GHG emissions for the region. The study argues that environmental and energy policy should acknowledge the distinctions between energy use and economic growth to maintain GCC economic growth. (Saqib, 2022c) used a dataset of Asian emerging economies from 1995 to 2020 to examine the dynamic nexus between energy use and economic growth. This work uses second-generation panel integration approaches to account for cross-sectional dependence and slope heterogeneity. Long-run equations are estimated using the mean, common correlated effects, and augmented mean groups. Economic expansion and fossil fuel sources usage worsen environmental deterioration, although sustainable energy mitigates the consequences over time.

Comparing data from multiple studies shows that findings vary substantially by approach and country. Most research in this field finds a linear link between sustainable energy use and economic growth. The panel threshold regression method developed by (Hansen, 1999) was utilized by (Chang et al., 2009) to come to the conclusion that high-growth countries can adjust to high energy prices by increasing their usage of sustainable energy, whereas low-growth countries are unable to do so. In their long-term results, researchers (Tugcu and Topcu, 2018) revealed that energy use and economic growth had a strong asymmetric relationship. This asymmetric linkage between sustainable energy and economic growth should be examined using the nonlinear ARDL approach developed by (Shin et al., 2014) and the methods proposed by (Hatemi-J, 2011). This research may examine a non-linear relationship between sustainable energy and economic growth, following (Tugcu and Topcu, 2018)**.** The effect of sustainable energy on economic growth may vary based on the levels of sustainable energy, labor, and capital employed in production.

3. DATA AND METHODOLOGY

We use sustainable energy use (SEU) to study the effects of SEC on economic growth above (below) a specified threshold. We use the log difference of GDP in billions of constant 2010 U.S. dollars for economic growth (GDP), gross fixed capital formation (GFCF), total labor force (TLF) in millions, and total REC and fossil fuel sources use (FFU). The World Bank WDI provide annual G7-countries and E7-countries data from 1992 to 2019. All of the variables used by (Apergis and Payne, 2011, 2012; Lin and Moubarak, 2014; Omri et al., 2015; Inglesi-Lotz, 2016; Bhattacharya et al., 2016) are the same ones used in this analysis. We can compare our results with those that use linear estimates because they use similar variables.

The descriptive statistics for the G7-countries and E7-countries are shown in Table 1. G7-countries have larger GDP, labor, capital, and use of sustainable and fossil fuel sources use on average, but GDP growth in E7 countries has been greater. All of the variables (labor, capital, sustainable energy use and fossil fuel sources use, and GDP) are positively and strongly connected with each other in the correlation matrix shown in Table 2.

Across all samples, output shows the strongest correlation to capital. Because they are used in manufacturing, input variables are also strongly and positively connected with one another. There are, however, a few notable exceptions to the rule. There is a correlation between the use of fossil fuel sources energy by the G7-countries and the use of sustainable energy, which suggests that sustainable

Table 1: Descriptive statistics

Variables	G7-countries				E7-countries			
	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum
Growth	0.0218	0.0301	0.2765	−0.0891	0.0456	0.0591	1.5123	−0.4981
GDP	5.9935	1.2634	8.9782	2.9857	2.9861	1.9032	9.0521	−1.4911
GFCF	24.8964	1.3342	28.8489	22.5036	22.2779	1.9745	27.0019	17.0078
TLF	2.1377	1.3776	5.0804	−1.8326	1.4030	1.7253	6.6683	−2.7830
SEU	11.305	1.5222	14.7352	6.2790	9.3728	2.0216	14.8923	2.4539
FFU	3.9143	0.2198	4.3412	3.8712	3.8921	0.8868	4.6723	0.5671

SD: Standard deviation, GDP: Dollars for economic growth, GFCF: Gross fixed capital formation, TLF: Total labor force, SEU: Sustainable energy use, FFU: Fossil fuel sources use

Table 2: Correlation matrix

Variables	GDP	GFCF	TLF	REC	FFU
G7-countries					
GDP	1.0000*				
GFCF	0.9671*	1.0000*			
TLF	0.8992*	0.8932*	1.0000*		
SEU	0.7189*	0.7001*	0.7012*	1.0000*	
FFU	0.3082*	0.3043*	0.2998*	0.4011*	1.0000*
E7-countries					
GDP	1.0000*				
GFCF	0.9578*	1.0000*			
TLF	0.8062*	0.7123*	1.0000*		
SEU	0.7078*	0.6761*	0.7923*	1.0000*	
FFU	0.5011*	0.5198*	0.0040	0.0872*	1.0000*

*Indicates the significance level at 1%. GDP: Dollars for economic growth, GFCF: Gross fixed capital formation, TLF: Total labor force, SEU: Sustainable energy use, FFU: Fossil fuel sources use

energy is gradually replacing fossil fuel sources at the aggregate level. In the countries that make up the E7-countries, labor and the use of sustainable energy as well as fossil fuel sources have strong ties to one another. The link between labor and capital in the G7-countries is the strongest, whereas the correlation between labor and use of sustainable energy in the E7-countries is the strongest.

This study examines growth and sustainable energy nexus. To build the econometric model, we assume the following production function as shown in equation-1.

$$GDP_{it} = f\left(GFCF_{it}, TLF_{it}, SEU_{it}, FFU_{it}\right) \quad (1)$$

where, GDP is economic growth, $GFCF_{it}$, TLF_{it}, REC_{it} and $NREC_{it}$ are gross fixed capital formation, total labor force, sustainable energy and fossil fuel sources for country i at time t respectively. In the presence of panel cointegration, the equation that can be used to describe the dynamic panel correction model is as follows in equation-2:

$$\Delta lnGDP_{it} = \alpha_i + \sum_{l=1}^{L}\beta_{1,i,l}\Delta lnGDP_{it-l} + \sum_{l=0}^{L}\beta_{2,i,l}\Delta lnGFCF_{it-l} + \sum_{l=0}^{L}\beta_{3,i,l}\Delta lnTLF_{it-l} + \sum_{l=0}^{L}\beta_{4,i,l}\Delta lnSEU_{it-l} + \sum_{l=0}^{L}\beta_{5,i,l}\Delta lnFFU_{it-l} + \beta_{5,i}\begin{pmatrix} \ln GDP_{it-1} - \partial_{0i} - \partial_{1i}\ln GFCF_{it-1} - \partial_{2i}\ln TLF_{it-1} \\ -\partial_{3i}\ln SEU_{it-1} - \partial_{4i}\ln FFU_{it-1}\end{pmatrix} + \varepsilon_{it} \quad (2)$$

where, Δ is the first difference and ∂_{0i} is an undetected country fixed effect

$$\Delta \ln GDP_{it} = \beta_{0,i} + \sum_{l=1}^{L}\beta_{1,i,l}\Delta \ln GDP_{it-l} + \sum_{l=0}^{L}\beta_{2,i,l}\Delta \ln GFCF_{it-l} + \sum_{l=0}^{L}\beta_{3,i,l}\Delta \ln TLF_{it-l} + \sum_{l=0}^{L}\beta_{4,i,l}\Delta \ln SEU_{it-l} + \sum_{l=0}^{L}\beta_{5,i,l}\Delta \ln FFU_{it-l} + \beta_{5,i}\ln GDP_{it-1} - \beta_{5,i}\partial_{1i}\ln GFCF_{it-1} - \beta_{5,i}\partial_{2i}\ln TLF_{it-1} - \beta_{5,i}\partial_{3i}\ln SEU_{it-1} - \beta_{5,i}\partial_{4i}\ln FFU_{it-1} + \varepsilon_{it} \quad (3)$$

We use a dynamic panel error correction threshold regression equation-3 in order to investigate the possible non-linear relationship between input variable and economic growth. The indicator function in below equation-4 depicts a sample separated by one threshold level.

$$\Delta \ln Y_{it} = \alpha_i + \beta_2^T X_{it} + \delta^T X_{it} I\left(q_{it} \le \gamma\right) + \varepsilon_{it} \quad (4)$$

Constant and individual error correction coefficients in equation-3 can be estimated in a single step by combining the long-run adjustment rate and long-run coefficients. We use the first-difference GMM approach that given by (Seo and Shin, 2016) to estimate equation-4 because of the prior evidence of bidirectional causality between sustainable and fossil fuel sources use and economic growth (Apergis and Payne, 2012). For the dynamic threshold panel model, the FD-GMM technique of (Seo and Shin, 2016) allows endogeneity in both regressors and threshold variables, while other methods either rely on the exogenous threshold variable or do not apply for the dynamic panel. Following (Arellano and Bond, 1991), we estimate equations 3 and 4 using the following moment conditions.

$$E\left(\Delta\varepsilon_{it} \ln GDP_{it-r}\right) = 0; E\left(\Delta\varepsilon_{it} \ln GFCF_{it-r}\right) = 0; E\left(\Delta\varepsilon_{it} \ln TLF_{it-r}\right) = 0; E\left(\Delta\varepsilon_{it} \ln SEU_{it-r}\right) = 0; E\left(\Delta\varepsilon_{it} \ln FFU_{it-r}\right) = 0 \quad (5)$$

Finally, we apply a sup-Wald test suggested by (Seo and Shin, 2016) to determine if there is a threshold impact. The critical values are obtained by using a bootstrap method in accordance with (Hansen, 1996).

4. RESULTS AND DISCUSSION

In order to investigate the long-term equilibrium connection between GDP, GFCF, TLF, SEU, and FFU, we employ methods from the second generation of panel cointegration, linear generalized method of moments, and threshold estimation. We first look at the data to see if there is any cross-sectional dependence, and if so, we utilize unit root tests that take this into account. A long-run equilibrium link between variables is then examined using panel cointegration tests of the first and second generation after assessing cross-sectional dependence. A series of panel unit root and panel cointegration tests are conducted before the GMM and threshold estimation are used to estimate the degree of integration of the variables in our model.

4.1. Cross-sectional Dependence Test

Cross-sectional independence (CSD) was assumed in the early work on unit roots and cointegration tests (Pesaran, 2014). For tests that assume cross-section independence, power use and size aberrations will emerge if the assumption is violated, which is common when looking at macro-level data. Before examining the link between energy use and economic growth, we first conduct a cross-sectional dependence test using (Pesaran, 2014) cross-sectional dependence test (Pesaran, 2014; Osman et al., 2016; Belaïd and Zrelli, 2019) cross-section dependence test findings are presented in Table 3. According to these findings, the null hypothesis of cross-sectional independence is strongly rejected for all variables examined at a 1% significance level for samples of G7-countries and E7-countries. Cross-sectional correlations between all of the variables were found. Table 3 provides the results of the cross-sectional dependence test of (Pesaran, 2014). The statistic has the distribution of a two-tailed standard normal when the null hypothesis of cross-sectional independence is taken into consideration.

Table 3: Cross-sectional dependence test

Variables	G7-countries		E7-countries	
	Statistic	Probability	Statistic	Probability
GDP	95.4563*	0.0000	241.0648*	0.0000
GFCF	53.1258*	0.0000	176.0917*	0.0000
TLF	86.4872*	0.0000	230.6652*	0.0000
SEU	78.8722*	0.0000	111.3726*	0.0000
FFU	39.9981*	0.0000	84.1787*	0.0000

*Indicates the significance level at 1%. GDP: Dollars for economic growth, GFCF: Gross fixed capital formation, TLF: Total labor force, SEU: Sustainable energy use, FFU: Fossil fuel sources use

4.2. Unit Root Tests

The first generation of panel unit root tests based on the assumption of cross-sectional independence (Maddala and Wu, 1999; Choi, 2001; Levin et al., 2002; Im et al., 2003) are inappropriate because they would suffer from size distortions and the ignorance of cross-sectional dependence (Pesaran, 2014). We therefore employ Pesaran's cross-sectionally augmented Im-Pesaran-Shin (CIPS) unit root test to account for the variables' cross-sectional dependence (2007). Results of the CIPS unit root test are shown in Table 4. At the 5% level of significance, we cannot rule out the unit root null hypothesis when we use the levels of the variables. Fossil fuel sources use for the G7-countries and E7-countries can be exempted from the null hypothesis of non-stationarity when we obtain the first-order differences of the variables used. Based on the data, we conclude that the variables are non-stationary at the level and stationary at the first difference levels. The outcomes of the CIPS examination of (Pesaran 2007) are detailed in the Table 4 below. In our analysis, we take into account a constant, a trend, and two lags. 1 percent, 5 percent, 10 percent are the critical values at 1 percent, 5 percent, and 10 percent level.

4.3. Panel Cointegration Tests

The findings of the panel cointegration test performed by (Westerlund, 2007) are presented in Table 5. A constant and a trend term are both fitted to the test regression. We have a combined total

Table 4: Cross-sectionally augmented Im-Pesaran-Shin-unit root test

Variables	G7-Countries				E7-Countries			
	Statistic	1%	5%	10%	Statistic	1%	5%	10%
I (0)								
GDP	−2.1005	−2.8341	−2.8724	−2.6692	−2.0506	−2.7612	−2.7221	−2.4321
GFCF	−2.3272	−2.8341	−2.8724	−2.6692	−2.4562	−2.7612	−2.7221	−2.4321
TLF	−1.9051	−2.8341	−2.8724	−2.6692	−1.6443	−2.7612	−2.7221	−2.4321
SEU	−2.1840	−2.8341	−2.8724	−2.6692	−2.0603	−2.7612	−2.7221	−2.4321
FFU	−1.6107	−2.8341	−2.8724	−2.6692	−2.0466	−2.7612	−2.7221	−2.4321
I (1)								
GDP	−2.8633***	−2.8379	−2.8811	−2.6692	−3.9858*	−2.7932	−2.7300	−2.4321
GFCF	−2.6405*	−2.8379	2.8811	−2.6692	−2.5435***	−2.7932	−2.7300	−2.4321
TLF	−4.3414***	−2.8379	2.8811	−2.6692	−2.9832*	−2.7932	−2.7300	−2.4321
SEU	−4.4517***	−2.8379	2.8811	−2.6692	−4.4232*	−2.7932	−2.7300	−2.4321
FFU	−2.6603*	−2.8379	2.8811	−2.6692	−2.6347**	−2.7932	−2.7300	−2.4321

*, **, ***Indicates the significance level at 1%, 5% and 10% respectively. GDP: Dollars for economic growth, GFCF: Gross fixed capital formation, TLF: Total labor force, SEU: Sustainable energy use, FFU: Fossil fuel sources use

Table 5: Panel cointegration test

Statistics	G_τ	G_a	P_τ	P_a
G7-countries	−2.6375** (0.0308)	−4.3684 (0.9080)	−7.4471 (0.7178)	−5.1012 (0.7048)
E7-countries	−4.0457 (0.647)	−0.5128 (0.2322)	−9.5593* (0.0000)	−0.5110 (0.1041)

*, **Indicate the significance level at 1% and 5% respectively

of three lags and leads working for us. The amount of bandwidth available from the kernel is determined by the integer that is closest to the value 4(T/100) 2/9. The assumption underlying the null hypothesis is that there is no instance of co-integration. The numbers enclosed in parenthesis are the bootstrap p-values, which can be relied on even when a cross-sectional dependence exists. (Pedroni, 2004) co-integration tests are flawed since all samples have cross-sectional dependence for all variables. Therefore, in order to determine whether or not there is a connection that exists over the long run between the variables, we use the cointegration tests that were developed by (Westerlund, 2007**).** Because the data presented in this article are cross-sectionally dependent, the cointegration test developed by (Westerlund, 2007) is suitable for this investigation. This test acknowledges the possibility of heterogeneity and was developed specifically to deal with cross-sectionally dependent data. The findings of the panel cointegration test conducted by Westerlund (2007) are presented in Table 6**.** (Persyn and Westerlund, 2018) stated that at least one unit (Gt and Ga) is tested for cointegration, whereas the panel tests (Pt and Pa) evaluate the alternative hypothesis that the panel is cointegrated. Almost all four test statistics reject the null of no cointegration at the 10% level for all G7-countries and E7-countries. Overall, the tests show that there is a long-term cointegration between the variables.

4.4. Linear GMM and Threshold Estimation

Table 6 provides estimations of the equation-3 using FD-GMM method. The lag length is one. The p-values are provided in brackets. Equations 3 and 4 are used to estimate the long-term

Table 6: Linear dynamic panel error correction

Variables	G7-countries	E7-countries
$\Delta\text{In}GDP_{it}$	−0.0129 (0.6532)	0.0370 (0.5912)
$\Delta\text{In}GFCF_{it}$	0.2031* (0.0000)	0.1379* (0.0000)
$\Delta\text{In}TLF_{it}$	0.4195** (0.0316)	−0.4098 (0.2078)
$\Delta\text{In}SEU_{it}$	−0.0005 (0.8112)	0.0205 (0.3452)
$\Delta\text{In}FFU_{it}$	−0.0150 (0.8516)	0.0583*** (0.0732)
$\Delta\text{In}GDP_{it-i}$	−0.6919* (0.0000)	−0.5255* (0.0000)
$\Delta\text{In}GFCF_{it-i}$	0.1501* (0.0000)	0.1374* (0.0004)
$\Delta\text{In}TLF_{it-i}$	1.0692* (0.0000)	0.5254* (0.0000)
$\Delta\text{In}SEU_{it-i}$	0.0068 (0.6743)	0.0901** (0.0169)
$\Delta\text{In}FFU_{it-i}$	0.1599 (0.1504)	0.0168 (0.5166)

*, **, ***Indicates the significance level at 1%, 5% and 10% respectively

linear and non-linear correlations, respectively, if there is a cointegration relationship. According to FD-GMM, the G7-countries and E7-countries are included in the linear specifications (i.e., estimations based on the first difference generalized methods of moments). This study focuses on the growth of sustainable energy $\Delta\ln SEU_{it}$) and lagged sustainable energy use $\ln SEU_{it}$, whereas the rest of the variables are mostly used as control variables. We used Equations 3 and 4 to estimate the results based on linear and threshold model estimations, respectively. Tables 6 and 7 show the results of linear and threshold estimations, respectively. When linear estimate methods are applied for both G7-countries and E7-countries, we find that the increase in sustainable energy use is not a significant factor of economic growth. For the G7-countries and E7-countries samples, the linearity hypothesis is rejected at the 5-percent and 1-percent levels using threshold estimation methods (see the P-value of Sup-Wald test in Table 6).

We find that the results from the G7-countries sample are in line with linear estimate methods, which show that the increase of sustainable energy growth has no meaningful effect on economic growth. As a result, no matter which model is used, sustainable energy's growth does not have a significant impact on economic growth, which is in line with the findings of (Omri et al., 2015) for Finland, and Switzerland**;** (Menegaki, 2011) for 27 European countries, (Chang et al., 2015) for Canada; Italy; and the United States.

Table 7 provides estimations of the equation-4 using FD-GMM method. The moment conditions used are listed in equation-5. The lag length is one. The *p*-values are provided in brackets. The threshold value that is found to be significant is reported in "threshold" for respective sample analysis. If regulators include the expenses of creating sustainable energy sources in the ultimate price of power, this negligible effect could be explained by the fact that public policies may raise the final cost of energy (Marques and Fuinhas, 2012). If a E7-countries' ln(SEU) falls below the threshold level of 8.8167, we find that growth in sustainable energy use negatively and significantly affects economic growth, whereas growth in sustainable energy use is positive and significant when a country's ln(SEU) rises above the threshold level of 8.8167. For countries where the literature had a negative impact, this

Table 7: Non-linear dynamic panel error correction regression results (sustainable energy use as a threshold variable)

Countries	G7-countries		E7-countries	
Threshold	9.9672**		8.8167***	
	Lower	Higher	Lower	Higher
$\Delta\text{In}GDP_{it}$	0.0419 (0.6263)	−0.4144* (0.0008)	−0.0954 (0.3889)	−0.2543*** (0.0692)
$\Delta\text{In}GFCF_{it}$	0.1352* (0.0000)	0.4231* (0.0000)	0.0279 (0.5128)	0.1801* (0.0000)
$\Delta\text{In}TLF_{it}$	0.49812 (0.1061)	0.3783 (0.3000)	0.4379 (0.3920)	−0.3465 (0.6123)
$\Delta\text{In}SEU_{it}$	−0.0201 (0.1160)	−0.0547 (0.2345)	−0.0537*** (0.0849)	0.2122* (0.0077)
$\Delta\text{In}FFU_{it}$	−0.2014** (0.0414)	0.0077 (0.9572)	0.0267 (0.6235)	0.0776 (0.4912)
$\Delta\text{In}GDP_{it-i}$	−0.7012* (0.0000)	−0.4101* (0.0003)	−0.4650* (0.0000)	−0.4434* (0.0000)
$\Delta\text{In}GFCF_{it-i}$	0.06992* (0.0023)	0.1170** (0.0197)	0.1436* (0.0058)	0.1204** (0.0391)
$\Delta\text{In}TLF_{it-i}$	0.7212* (0.0000)	0.5125* (0.0036)	0.4216* (0.0046)	0.3808** (0.0101)
$\Delta\text{In}SEU_{it-i}$	0.0121 (0.6237)	−0.0042 (0.8741)	0.0819 (0.1553)	0.1097 (0.1821)
$\Delta\text{In}FFU_{it-i}$	0.3001*** (0.0815)	−0.1032 (0.4867)	−0.0012 (0.9837)	0.0724 (0.2956)
SW (P)	0.0297		0.0049	
SW statistics	29.7892		51.9822	

*, **, ***Indicates the significance level at 1%, 5% and 10% respectively. SW: Sup wald

research provides an explanation (Marques and Fuinhas, 2012; Ocal and Aslan, 2013; Bhattacharya et al., 2016). Because of the high upfront investment costs and capacity storage issues associated with sustainable energy sources, countries that use less sustainable energy than the threshold face slower economic growth. Sustainable energy use can have a substantial impact on economic growth in E7 countries if those countries achieve a certain level of sustainable energy use and begin to benefit from lower sustainable energy use prices. To put it another way, we were able to determine why two distinct lines of research came to opposite conclusions (i.e., the literature that found a positive and negative effect of sustainable energy on economic growth).

5. CONCLUSION AND POLICY RECOMMENDATIONS

Sustainable energy sources such as wind, solar, and hydropower are gradually replacing fossil fuels in general use. This trend is expected to continue. This research does experimental tests to determine if there is any kind of non-linear link between sustainable energy usage and economic growth. The experiments are conducted using a threshold model, with sustainable energy use serving as the threshold variable. Only G7-countries show a positive correlation between sustainable energy and economic growth in the linear models used here. E7-countries' economic growth appears to be unaffected by the growth of sustainable energy, according to linear models. E7-countries, on the other hand, would gain greatly from investing in sustainable energy sources if their use of sustainable energy above a particular threshold, as long as the threshold models were used. Increasing the share of sustainable energy in a country's energy mix has a detrimental impact on economic growth in emerging countries. If E7 countries increase their use of sustainable energy, they will not be destined to a slowdown in their economy, as our data show, because they can begin to reap the benefits of increased sustainable energy use after reaching a specific threshold level of use. In other words, the short-term harm caused by low levels of sustainable energy use could be offset in the long run by increased reliance on sustainables in these countries. Increasing the deployment of sustainable energy has been linked to more effective governance (Cadoret and Padovano, 2016) as well as energy market liberalization (Nicolli and Vona, 2019). Sustainable energy use is critical for economic growth, and our findings may help inspire this course of action, even though the early investments may have a detrimental impact on growth in E7 nations. Global warming causes distress and requires major remedies. Shifting to sustainable resources and encouraging public-private partnership investment in green ventures are viable alternatives (Yang et al., 2022).

Based on the limits and findings of this work, there are numerous opportunities for future research. First, we look at the aggregate effects of sustainable energy use on economic growth at the country level, without considering sector-specific effects. It will be fascinating to see if sustainable energy utilization affects economic growth differently across sectors. Using panel data, we analyze the sustainable energy use threshold; a future study may use time series threshold models to examine country-specific thresholds (region). Because we used yearly data, we can't predict how quickly individuals would transfer to (or away from) sustainable energy sources in response to price changes. It will be interesting to see how corporations and countries react to variable energy prices and if they decide to use more sustainable energy. A future study could analyze if socio-economic variables like oil prices, GDP per capita, and CO_2 emissions have threshold levels at which their effect on sustainable energy use differs. Finally, we consider sustainable energy use. Depending on the cost of sustainable energy generation, sustainable use's impact on economic growth may vary. Economic growth in countries using alternative, sustainable energy sources may disclose which ones are more beneficial.

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