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Energy efficiency, cleaner energy and energy related prices: evidence from dynamic generalised method of moments

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ABSTRACT

Environmental degradation is one of the main concerns for the countries across the globe, where energy efficiency (E.N.E.F.) is regarded as one of the substantial remedial measures. Still, the factors affecting E.N.E.F. is not extensively explored in the empirical literature. In this sense, the current study tends to analyse the influencing factors of E.N.E.F. in case of the G7 economies throughout 1990–2020. Since this study is dealing with the panel data, therefore, various panel data specifications are used, which validates the slope heterogeneity, panel cross-section dependence (C.D.), and the existence of cointegration between E.N.E.F., economic growth, renewable energy, energy related inflation, and political risk index (P.R.I.). Due to mixed integrating order, this study employed Cross-Sectional Autoregressive Distributed Lag (C.S.-A.R.D.L.) approach, which reveals that all the variables are significant and positive factors of E.N.E.F. in both short and long-run. Also, the results reveals the convergence of model towards the equilibrium with 83.7% speed of adjustment. To tackle the panel data issues such as slope heterogeneity and C.D., this study employed Dynamic Common Correlated Effects–Generalised Method of Moment (D.C.C.E.–G.M.M.), which also indicates the positive and significance influence of the selected variables on E.N.E.F. The estimated results are validated by Augmented Mean Group (A.M.G.) estimator. Moreover, bidirectional causal nexus is found between E.N.E.F. and regressors (economic growth, renewable energy, energy related inflation, and P.R.I.). This study also provides relevant policy measures at the end.

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1. Introduction

Energy is the chief input in the economic production processes that affect pecuniary security provided by the demand for energy management (Valizadeh et al., 2018). Recently, the demand reverberation and supply constraints have raised prices around the world. However, efficient energy can be resourceful in overcoming the energy

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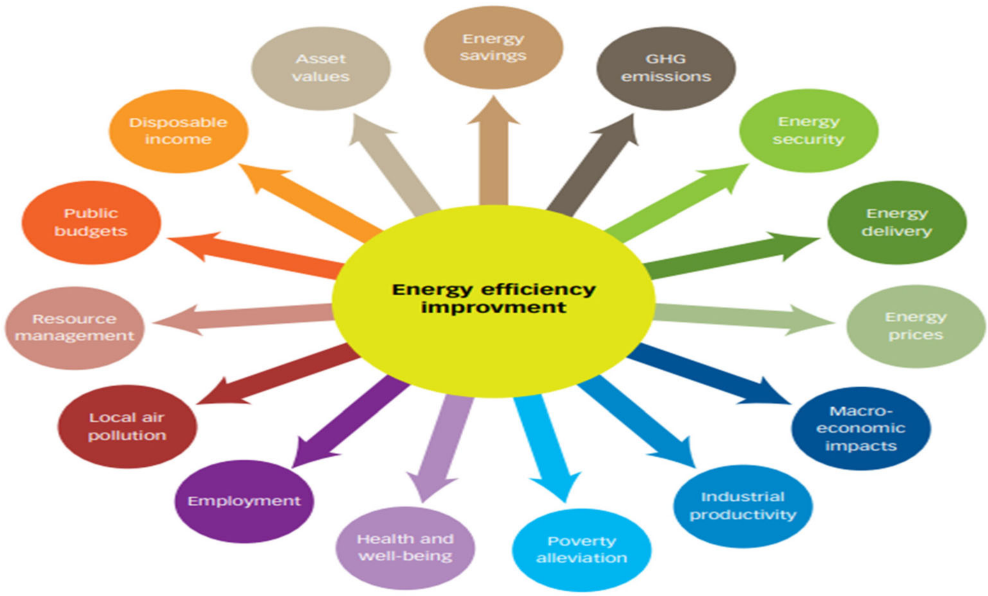

Figure 1. Multiple benefits of energy efficiency.
Source: Singh (2016).

deficit together with promoting clean energy, maintaining steady energy prices, and climate change mitigation targets. For that reason, energy efficiency (E.N.E.F.) reduces energy consumption which aids in limiting energy-related prices and providing discounted energy (Jaeger et al., 2022).

E.N.E.F. is now considered one of the sources of clean energy economically. It not only reduces energy costs but also limits harmful greenhouse emissions. E.N.E.F. is referred to as less amount of energy required for the same task done providing the same results (IEA, 2014). There are several long-term benefits of conserving E.N.E.F., most of which are exemplified in Figure 1 of the manuscript. Attributable to Singh (2016) E.N.E.F. is an untapped energy source that can restrain energy demand by almost 10% by the year 2040. Moreover, it can be useful in tackling global challenges such as environmental problems, energy security, poverty, and social and fiscal pressures. It is a global conversed area for climate change and sustainable development. Anyhow, certain implementation barriers along with poor governance and weak markets have prohibited E.N.E.F. to reach maximum potential. Hence, the present study aims to determine the relationship between the study factors and E.N.E.F. which help in improving E.N.E.F. for sustainability and acquiring Sustainable Development Goals, especially SDG 7.

In the existing literature, several studies examined the linkage between economic development, renewable energy, and E.N.E.F. The upsurge in the efficient form of energy positively contributed to economic development. For instance, in a study in Canada where a dollar spending on E.N.E.F. contributes to a minimum 5 dollars increase in G.D.P. (Singh, 2016; Zakari et al., 2022). While Kolosok et al. (2021) observed the positive assembly between renewable energy share and E.N.E.F. Additionally, a rare number of authors have examined the nexus between energy prices and E.N.E.F. which is essential for energy/economic policy framework and economic growth (Borzuei et al., 2022; Hang & Tu, 2007). However, there is still a lot of research required to scrutinise the potential of E.N.E.F. along with effective strategies and their implementation. Besides, analysing different factors that influence E.N.E.F. Numerous economic, social, financial, and environmental factors impact the energy sector. Therefore, the study aims to determine those factors by expanding the discussion on this area.

The study's sole purpose is to investigate the impact of cleaner energy and energy-related prices on E.N.E.F. For this, the authors employed various variables such as Energy prices, Energy consumer price index (C.P.I.E.), Renewable energy, Gross Domestic Product, and Political-economical risk and E.N.E.F. from the period 1990 to 2020. The association between G.D.P., renewable energy, and E.N.E.F. is a decade-long discussed topic. However, the inclusion of new explanatory variables extends the conversation. Hence, the article analyses the above-said relationship with novel variables with modern econometric estimation techniques. This purpose is stimulated due to an increase in energy prices after the pandemic and increasing energy demand across countries.

The motivation for the study lies in evaluating the impact of all explanatory variables on E.N.E.F. E.N.E.F. is necessary to meet growing energy demands across the world in an economical way without harming the environment. Moreover, it fosters sustainable growth and environment besides providing advantages manifold illustrated in Figure 1. The study findings support providing determinants for E.N.E.F. The political-economic risk helps in maintaining a stable economy for efficient energy because any economic or political risk affects the energy policies and international relations while non-renewable energy consumption and variation in energy-related prices negatively and substantially contribute to E.N.E.F. For this reason, the study intensifies assessing cleaner energy and steady energy-related prices with a stable economy for sustainable growth and the environment.

The study is significant in re-visiting the influence of renewable energy and economic growth on E.N.E.F. The increasing environmental problems due to non-renewable energy have caused academicians and environmentalists to explore the aspects of an efficient form of energy and renewable sources for sustainability. Hence, the present study findings are significant in re-evaluating the role of renewable energy and economic growth in E.N.E.F. Second, the originality of the research is that the study comprises innovative variables (Energy C.P.I.E. and Political-economical risk) for a thorough analysis of E.N.E.F., which signifies the novelty and importance of the research. Because these factors are novel and have a substantial part in energy transition together with providing efficient energy (Hang & Tu, 2007).

The study tends to contribute to the literature in threefold ways. First, to the authors' best knowledge the primary contribution of the study is in examining the role of the energy C.P.I.E. and political-economical risk on E.N.E.F. The empirical analysis on E.N.E.F. needs to be updated, therefore the authors have employed the abovementioned novel variables for the first time for the evaluation of E.N.E.F. for sustainable development. Second, E.N.E.F. plays a significant role in climate change, environmental quality, stability, and sustainability. Therefore, the current research contributes by investigating the association between Energy prices, Renewable energy, G.D.P., Energy C.P.I.E., and Political-economical risk on E.N.E.F. by expanding the empirical literature with updated data period from 1990 to 2020. Third, the study utilises efficient econometric analysis techniques such as the cross-sectional Autoregressive distributive lag technique (C.S.-A.R.D.L.) and Dumitrescu-Hurlin Causality analysis for scrutinising the association among the variables.

The rest is prearranged as follows. The next section is about reviews of existing literature. Sections 3 and 4 document the data, model, methodology, and results with discussions respectively. Lastly, section 5 deals with conclusions and policy implications.

2. Literature review

In recent times, global economies have a major concerned about the environmental degradation and global warming. The major reason for such environmental issues includes the extensive carbon and greenhouse gas emissions. The existing literature reveals that there are numerous factors that could substantially enhance the emissions level in the atmosphere. Specifically, the use of fossil fuel for heating (Jiang, Yu, et al., 2022) and combustion is a primary source of increased pollution in the region, which is obtained from natural resources and could influence economic growth, but are harmful for environmental quality (Rahim et al., 2021; Shen et al., 2021). However, the existing literature also provides various measures and policies to tackle environmental issues and promote environmental sustainability. For instance, fiscal decentralisation (Khan, Ali, et al., 2021), financial inclusion (Qin, Raheem, et al., 2021), exports (Khan, Ali, Jinyu, et al., 2020), renewable energy electricity (Qin, Hou, et al., 2021), lower composite risk (Khan, Murshed, et al., 2021), investment in energy industry (Luan et al., 2022), eco-innovation (Khan, Ali, Umar, et al., 2020; Khan, Malik, et al., 2020), environmental related policy instruments and environmental regulations (Khan et al., 2019; Shahzad et al., 2021) and environmental research and development (Jiang, Chishti, et al., 2022) are regarded as remedial measures for environmental recovery.

On the other hand, E.N.E.F. is now the most conversed subject for sustainability around the world. The improvement in efficient energy and policy framework helps in achieving sustainable development goals (Sinha et al., 2022). Moreover, the technological advancement and effective implementation of environmental taxes for an efficient form of energy have a substantial adverse influence on degrading environmental quality (Doğan et al., 2022; Jahanger et al., 2022). The overall literature on E.N.E.F. with explanatory variables is uncommon. However, the following sets of studies in this segment will elaborate on the associations and aspects of variables under consideration with E.N.E.F.

The association between energy prices and E.N.E.F. is limited. A few authors have examined the nexus which is elaborated in the succeeding empirical evidence. However, the energy C.P.I.E. and E.N.E.F. association are not a much-discussed area in the existing literature. E.N.E.F. is essential for the formulation of energy policies. Tajudeen (2021) emphasised that energy-specific prices have asymmetric responses whereas, total energy prices have an insignificant influence. Hang and Tu (2007) analysed that the effect of energy prices on E.N.E.F. is asymmetric with time in the case of China. The increase in energy prices tends to boost E.N.E.F. which is also an effective policy tool. Jacobsen (2015) examined that energy prices have no substantial impact on the efficient form of energy usage. Additionally, the results further suggested that energy prices have restrictions when they impact the investments in residential E.N.E.F. In an empirical study for Iran, Valizadeh et al. (2018) explored that energy prices have a positive and significant impact on energy consumption efficiency. However, the increase in energy prices decreases the ratios of energy-capital and energy-output. Besides the energy intensities negatively influence energy (oil) prices (Gamtessa & Olani, 2018). Likewise, Chen et al. (2016) observed a significant association between energy prices and E.N.E.F. in the long and short run in the case of Taiwan. For that circumstance, it plays a substantial role in influencing economic growth (Borzuei et al., 2022). Nonetheless, in contrast, Pach-Gurgul et al. (2021) observed a negative and significant effect of energy prices on the intensity of energy in V4 economies.

E.N.E.F. and renewable energy are essential elements for the transition of energy (Vega et al., 2022). Ponce and Khan (2021) observed the negative effects of E.N.E.F. and renewable energy on the emissions of carbon. E.N.E.F. and renewable energy both are significant for sustainable green growth (Zhao et al., 2022). Chen et al. (2022) discovered that investments in renewable energy sources are helpful in efficient energy as one of the essential factors in E.N.E.F. Further, the causal direction flows from E.N.E.F. to renewable energy resources. Kolosok et al. (2021) examined the positive connection between renewable energy share and E.N.E.F. in Europe. Wang et al. (2020) also examined some substantial impacts of E.N.E.F. in contributing to increasing renewable energy. The innovative study in the case of Turkey by Apak et al. (2017) emphasised promoting renewable energy that aids in increasing E.N.E.F. E.N.E.F. and renewable energy significantly enhance environmental quality. Further, Usman and Balsalobre-Lorente (2022) and Balsalobre-Lorente et al. (2022) emphasised that renewable energy has a substantial role in limiting pollution emissions with a one way directional relationship. The novel study by Mungai et al. (2022) suggests that encouraging renewable energy and E.N.E.F. promotes green growth, economic development, and environmental sustainability (Zhao et al., 2022). Moreover, in constructing energy-efficient buildings renewable energy plays a substantial role by utilising energy-efficient types of building equipment (Chel & Kaushik, 2018).

Zhu and Lin (2022) explained that the pressure of economic growth hampers the efficiency of energy. The empirical findings demonstrated a negative linkage between the said variables. In contrast, Cantore et al. (2016) studied the technological impact of E.N.E.F. in 29 developing economies. The results suggested that E.N.E.F. is essential for economic development and triggers productivity in the country. Because technological advancement aid in providing an effective form of energy besides having a substantial influence on degrading environmental quality (Jahanger et al., 2022). Likewise, Bataille and Melton (2017) analysed that E.N.E.F. enhancements tend to increase the economic growth of the economy. Additionally, it changes and re-orients economic structure from capital-intensive to labour-intensive sectors. Rajbhandari and Zhang (2018) analysed that E.N.E.F. is important in creating growth aids in developing nations. The empirical finding depicted that in high-income countries, there is a uni-directional granger causal relationship between economic growth and E.N.E.F. While bi-directional causal association runs from G.D.P. to energy intensity in lower and upper-income countries. Moreover, in innovative research, a positive linkage between E.N.E.F. and economic growth was observed. The increase in E.N.E.F. contributes to economic growth (Adom et al., 2021; Zakari et al., 2022).

Due to the scarcity of empirical literature on economical-political risk and E.N.E.F., the following set of studies elaborates on the aspects of political-economic risk and E.N.E.F. Political risk has a critical role in the energy sector's hindrance (Truscott, 2008). Adebayo et al. (2022) observed that political risk positively and significantly affects environmental degradation. Likewise, economic and financial risks have also adverse impacts on environmental quality by increasing carbon emissions. However, E.N.E.F. with minimum political and economic risk ensures environmental quality and limits carbon emissions (Wang et al., 2022). Further, a rising political and financial risk reduces the sustainability and growth of an economy (Kirikkaleli & Onyibor, 2019).

2.1. Literature gap

The abovementioned scrutiny of prevailing literature depicts that E.N.E.F. is a less debated area concerning study variables and more research is needed for an in-depth analysis of an effective and efficient form of energy. Therefore, the present research is novel in contributing to the literature for scrutinisation of under consideration variables on E.N.E.F. To fill this gap the authors, incorporated variables like Energy C.P.I.E. and Political-economical risk for evaluating their role in E.N.E.F. The price indices and political risk significantly impact efficient energy (Kirikkaleli & Onyibor, 2019; Wang et al., 2022). Second, the discussion on E.N.E.F. is a widely concerned subject for sustainable environment and growth. Hence, the present study extends the debate by examining the influence of Energy related inflation, Renewable energy, G.D.P., Energy C.P.I.E. and Political risk on E.N.E.F.

3. Data and methodology

Following the study's objectives and literature as mentioned above, this study uses four variables against the E.N.E.F. in the empirical model. Specifically, the aim of this study is to discover the factors affecting E.N.E.F.: therefore, the E.N.E.F. is taken as G.D.P. per unit of energy use (P.P.P. $per kg of oil equivalent). Whereas the explanatory factors include economic growth – captured via the gross domestic product (G.D.P.: measured as constant US$2015), renewable energy electricity output (R.E.E.L.), political risk index (P.R.I.), and the energy related C.P.I.E. Except for the R.E.E.L. and C.P.I.E. data, which is extracted from the P.R.S. group[1] and O.E.C.D.,[2] respectively, Data for all the variables is extracted from the World Development Indicators of the World Bank.[3] The data covers an extended and available period from 1990 to 2020 for the group of seven (G7) economies, including Canada, the United Kingdom, the United States, Japan, Italy, France and Germany.

Following the study of Cantore (2017), this study develops the following general model of the study:

$$ENEF_{,it} = f(GDP_{it}, REEL_{it}, PRI_{it}, CPIE_{it})$$

The model stats that G.D.P., R.E.E.L., P.R.I. and C.P.I.E. combinedly are the functions of E.N.E.F., where the general model could be transformed into regression form as below:

$$ENEF_{it} = \alpha_1 + \beta_1 GDP_{it} + \beta_2 REEL_{it} + \beta_3 PRI_{it} + \beta_4 CPIE_{it} + u_{it} \tag{1}$$

where the equation indicates that α and $\beta's$ are the intercept and slopes, respectively, whereas u is the model's random error term. Besides, the subscript shows cross-sections – captured via '*i*' and time series – captured via '*t*'.

3.1. Estimation strategy

Since this study deals with the panel data, therefore, it is pertinent to utilise panel data approaches. Assessing the Slope heterogeneity and Cross-section Dependence (C.D.) of the chosen Panel data is the first step in this investigation. Countries on the panel may have similarities in certain areas while displaying differences in others. In contrast, in econometric analysis, the homogeneous properties of economies might result in skewed predictions, especially in panel estimations (Çoban & Topcu, 2013; Wei et al., 2022). Consequently, it is essential to analyse the homogeneous or heterogeneous properties of the concerned group of economies, which is G7 in this case. In this context, we used the slope coefficient homogeneity (S.C.H.) test developed by Pesaran and Yamagata (2008) while addressing coefficients similar to the null hypothesis: slope coefficients are homogenous. The basic formulations for the above specification are presented below:

$$\hat{\Delta}_{SCH} = (N)^{1/2}(2k)^{-1/2}\left(\frac{1}{N}\acute{S} - K\right), \tag{2}$$

$$\hat{\Delta}_{ASCH} = (N)^{1/2}\left(\frac{2K(T-K-1)}{T+1}\right)^{-1/2}\left(\frac{1}{N}\acute{S} - 2K\right), \tag{3}$$

where $\hat{\Delta}_{SCH}$ represent the S.C.H. and $\hat{\Delta}_{ASCH}$ represents adjusted S.C.H.

Numerous variables may enhance a country's reliance on the rest of the globe in this globalised world, where change in a specific variable in one economy could have a spillover impact on the variable in ither country or region. However, ignoring cross-sectional dependency may result in inconsistent and misleading estimates (Wei et al., 2022). Therefore, we used the C.D. test developed by Pesaran (2021) to examine cross-section reliance among the G7 nations. The said test is provided in general form as below, which assumes the independence of cross-sections:

$$\mathrm{CD}_{Test} = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{k=1+i}^{N} T_{ik}, \tag{4}$$

As soon as the findings for C.D. and slope heterogeneity are achieved, the unit root or stationarity of the chosen variables is examined. The handling of data including both cross-sections and time-series must remain stationary over time. In this respect, we used the second-generation panel unit root test, i.e., the C.I.P.S. unit root test produced by Pesaran (2007), which addresses the problem of the heterogeneous panel and also handles the challenge of C.D. between the units. The unit root test is generally based on the factor modelling approach proposed by Pesaran (2006). However, the C.I.P.S. followed that approach by adding leads and lags to the A.D.F. regression for tackling the serial correlation issue. As the null hypothesis, this test assumes the existence of the unit root in the data.

After using diagnostic and stationarity tests, this research explores the equilibrium connection between the variables in the long term. As a result of the diagnostic tests revealing heterogeneous slope coefficients and validating C.D. Therefore, this research employs a suitable empirical method that accounts for the aforementioned difficulties. Particularly, Westerlund's (2007) error correcting approach is implemented. This test assumes the error correction term has a value of zero (null hypothesis). In addition, this test is effective in that it considers both the mean group (M.G.) and the panel statistics:

$$G_\tau = \frac{1}{N} \sum\nolimits_{i=1}^{N} \frac{\hat{\alpha}_i}{S.E\hat{\alpha}_i}, \tag{5}$$

$$G_a = \frac{1}{N} \sum\nolimits_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)}, \tag{6}$$

where both Equations (5) and (6) estimates the group mean statistics.

$$P_\tau = \frac{\hat{\alpha}}{S.E\widehat{(\alpha)}}, \tag{7}$$

$$P_a = T.\hat{\alpha}, \tag{8}$$

where Equations (7) and (8) estimates the panel statistics.

Common shocks, such as the global financial crises of 2008–2009, the oil price shocks of 1997–1999, etc. are associated with a number of reasons related to cross-sectional dependence. If such common variables were not noticed in association with the regression, this could result in inaccurate estimations. The cross-sectional augmented autoregressive distributed lag (C.S.-A.R.D.L.) is a viable solution for overcoming C.D., slope heterogeneity, non-stationarity, and endogeneity since it employs a dynamic common correlated effects estimator (Khan, Ali, Umar, et al., 2020; Yao et al., 2019). In comparison to other estimators such as the M.G., augmented mean group (A.M.G.), pooled mean group (P.M.G.), and common correlated effect mean group (C.C.E.M.G.), Chudik and Pesaran (2015) have created the C.S.-A.R.D.L., which efficient is more efficient and robust approach (Danish, 2020; Li et al., 2020). Typically, the C.S.-A.R.D.L. formulation is expressed as follows:

$$Y_{it} = \sum_{I=0}^{Pw} \alpha_{I,t}, Y_{i,\ t-I} + \sum_{I=0}^{Pz} \beta_{I,i} Z_{i,t-I} + \sum_{I=0}^{Px} \gamma_i, I\overline{X}_{t-I} + \varepsilon_{i,t}, \tag{9}$$

where the equation above is the expanded version of C.S.-A.R.D.L., wherein $\overline{X}_{t-I} = \overline{Y_{i,t\bar{I}}}, \overline{Z_{i,t\bar{I}}}$ represents the means of the examined variables for the dependent variable and regressors. Besides, Pw, Pz and Px represent the lags of the variables under consideration. In addition, Y_{it} indicates the dependent variable, which is E.N.E.F. in this research study. Simultaneously, Z_{it} captures all the explanatory factors under consideration, namely: economic growth (G.D.P.), R.E.E.L., energy related inflation and P.R.I.

To further explore the long-run elasticities, this study utilise the Common Correlated Effects under the Generalised Method of Moments (D.C.C.E.–G.M.M.) proposed by Neal (2015). Specifically, Neal (2015) updated Chudik and Pesaran (2015) Dynamic Common Correlated Effects model. Unlike Ordinary Least Squares (O.L.S.), D.C.C.E.–G.M.M. takes into consideration the territory-specific fixed effect as well as the M.G. characteristics under the G.M.M. to allow for the possible endogeneity and heterogeneity. D.C.C.E.–G.M.M. incorporates the variables' lags as a tool to mitigate possible bias caused by the reverse-causality issue. D.C.C.E.–G.M.M. is hence resistant to the presence of endogenous explanatory variables. Even when given the limited sample characteristics, Monte Carlo simulations demonstrate the accuracy of the predicted parameters using the D.C.C.E.–G.M.M. method. This strategy may handle the issue of cross-sectional dependence resulting from shared observers and undetected shocks.

Once the empirical results are achieved, this study tends to analyse the robustness of the model. Therefore, this study employs the A.M.G. estimator proposed by Eberhardt (2012). The main reason for selecting A.M.G. as a robustness test is that it tackles the panel data issues such as C.D., slope heterogeneity, and non-stationarity. In addition to the robustness test, this study also tends to analyse the causal association between E.N.E.F. and the regressors as the earlier estimators lacks demonstrating the causal nexus between the variables. In this sense, this study uses the Dumitrescu and Hurlin (2012) panel Granger causality heterogenous test, which is more powerful in dealing the discussed panel data issues.

4. Results and discussion

This section reports the empirical results obtained via panel data estimating approaches discussed in Section 3. Since the current research is dealing with panel data: therefore, it is pertinent to employ the panel diagnostic tests, including the slope heterogeneity and C.D. The estimated results for both the tests are given in Table 1. From the estimated results, this study observed that both the S.C.H. and A.S.C.H. have a statistically significant values at 1% level. Such significant estimates rejects the

Table 1. Slope heterogeneity and cross-section dependence.

Homogenous/Heterogeneous slope coefficient testing				
$\tilde{\Delta}$			$\tilde{\Delta}^{Ajusted}$	
7.950***			8.853***	
Pesaran (2021) Cross-Section Dependence Test				
ENEF	REEL	CPIE	GDP	PRI
22.847***	17.397***	6.803***	23.498***	5.967***

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own estimation from the data obtained from the given sources.

Table 2. Unit root testing.

	Trend and intercept		
Variable(s)	I(0)	I(1)	Order of integration
ENEF	−2.462	−5.484***	I(1)
REEL	−3.443**	–	I(0)
CPIE	−4.238***	–	I(0)
GDP	−1.964	−4.861***	I(1)
PRI	−4.861***	–	I(0)

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own estimation from the data obtained from the given sources.

null assumption of slope homogeneity. Instead, the slopes are heterogenous. Similarly, the estimated results of the Pesaran (2021) C.D. test also provides highly statistically significant values for each variable under consideration. Therefore, the null hypothesis of this test shall also be rejected and it is concluded that the C.D. is valid in the G7 economies. Specifically, the C.D. asserted that change in any of the selected variable could have a spillover effect on the variables of other G7 economies.

After the validation of slope heterogeneity and panel C.D., this study tends to utilise appropriate unit root estimator that could deals the said issues. In this regard, this study uses the Pesaran (2007) C.I.P.S. unit root test and the estimated results are given in Table 2. The results reports that R.E.E.L., C.P.I.E., and P.R.I. are statistically significant at 5% and 1% levels, where as E.N.E.F. and G.D.P. are found non-significant. Therefore, the earlier variables rejects the null hypothesis of unit root presence at the leveled data. In order to estimates the long-run elasticities, each variable must be stationary. Therefore, the current study also analysed the unit root on first difference for the both E.N.E.F. and G.D.P. This time, both the variables are stationary, which allow authors to examine the long-run equilibrium relationship between the variables under-consideration.

To investigate the cointegration between the variables under consideration, this study performs the Westerlund (2007) E.C.M. approach, which is relatively efficient than the other existing measures. Table 3 reports the empirical results of the said test, which gives estimated values for both the group and panel statistics. From the examined results, this study noted that both the group mean (G_t and G_a) statistics, and the panel (P_t and P_a) statistics are highly statistically significant and is sufficient for rejecting the null hypothesis. Specifically, this test clarifies that the E.C.T. is not equal to zero, which further reveals that the model tends to approach equilibrium in the longer run.

Table 3. Cointegration test.

Westerlund (2007) cointegration test		
Statistic	Value	Z-value
G_t	−6.407***	−11.392
G_a	−35.251***	−9.439
P_t	−14.918***	−8.399
P_a	−33.863***	−10.042

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own estimation from the data obtained from the given sources.

Table 4. CS-ARDL.

Short-run outcomes		
Variables	Coefficients	Standard error
ΔGDP	0.468**	0.2151
ΔREEL	0.195***	0.0603
ΔCPIE	0.0141***	0.0021
ΔPRI	0.1934***	0.0471
ECM(−1)	−0.837***	0.0687
Long-run outcomes		
GDP	0.577**	0.2544
REEL	0.237***	0.0666
CPIE	0.0161***	0.0035
PRI	0.224***	0.0423

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own estimation from the data obtained from the given sources.

After validating the long-run equilibrium relationship between the variables, this study tends to estimate the coefficient values for each variable considered. Nonetheless, this study noted that the variables follows mixed order of integration, where some variables are stationary at I(0), while other are stationary at I(1). Therefore, this study utilises the C.S.-A.R.D.L. approach which is effective in terms of tackling the mixed order integration problem in the panel data, provides the short and long-run elasticities, and also reports the error correction term. The estimated results of the said test is reported in Table 4. The estimated results asserted that all the variables, i.e., G.D.P., R.E.E.L., C.P.I.E. and P.R.I. positively and significantly influences the E.N.E.F. in the G7 economies in both the short-run and long-run. Specifically, the results indicates that a 1% increase in G.D.P. significantly enhances the E.N.E.F. by 0.468 and 0.577% in the short-run and long-run, respectively. The positive association between the latter variables is also evident and consistent to the empirical results of Bataille and Melton (2017), Rajbhandari and Zhang (2018) and Adom et al. (2021). The reason behind the positive impact of economic growth on ENEF is that the increasing economic growth enhances the income level as well as investment. Due to increase in the income level, the authorities as well as industrialists tend to use lesser energy while producing the same amount of energy. As a result, the E.N.E.F. not only reduces the manufacturing cost, but also enhances environmental quality. Besides, R.E.E.L. imposes a positive impact on E.N.E.F. with a magnitude of 0.195% in the short-run and 0.237% in the long-run. In order to achieve environmental sustainability, governments usually imposes strict environmental regulations that targets environmental sustainability by reducing fossil fuel consumption and enhancing the share of renewable energy. Following the path of sustainability, the industrial sector also, enhances investment in the E.N.E.F. sector to maintain the same level of output while minimising the energy input. The empirical findings of this study is found consistent the empirical results of Chen et al. (2022), and Apak et al. (2017), which reveals that renewable energy increase plays a substantial role in increasing E.N.E.F. in the regions.

Concerning energy related prices or inflation, this study found that enhancement in the C.P.I.E. significantly enhances E.N.E.F. by 0.0141% in the short-run, while 0.0161% in the long-run. The estimated results are found highly statistically significant at 1% level. Inflation in the energy related resources forces the industrialists and manufacturers to reduce the energy consumption while maintaining the same level of output. In this sense, the industry transforms towards the adoption of energy efficient equipment and resources. The positive influence of energy related prices on E.N.E.F. is also evident in the empirical studies of Valizadeh et al. (2018) and Chen et al. (2016). In order to enhance E.N.E.F., the energy related inflation is an effective tool, which is already found appropriate in case of China (Hang & Tu, 2007). Lastly, this study found that P.R.I. significantly enhances E.N.E.F. by 0.1934% in the short-run and 0.224% in the long-run. The reason behind the positive influence of P.R.I. on E.N.E.F. is that the increased political instability causes instability or volatility in natural resources commodities prices, which further lead to postponement of investors and industrialists to invest in the energy sector. Therefore, the industrialists tends to utilise energy efficient resources to reduce the extensive use of energy. Therefore, the political risk could also have a positive role in the environmental quality sustainability as evidence in the study of Wang et al. (2022). Since all the variables substantially enhances E.N.E.F. in the G7 economies, which not only leads to energy and environmental sustainability, but also enhance economic growth (Borzuei et al., 2022). Apart from the discussion above, this study noted that the magnitude of the influence is greater in the long-run, relative to the short-run. While the error correction term is found −0.837. This indicates that each year passing, the equation or model is converging towards the equilibrium with 83.7% speed of adjustment.

Apart from the C.S.-A.R.D.L., this study also uses the D.C.G.E.–G.M.M. to estimate the long-run elasticities. The importance of using this test is that unlike the C.S.-A.R.D.L., this test is effective in dealing the slope heterogeneity, cross-section-dependence, and endogeneity issues. Therefore, is dealing with that issue, the estimated results are reported in Table 5. The estimated results illustrate that all the

Table 5. Dynamic common correlated effects estimations (DCCE-GMM).

Variables	Coefficients [Std. error]
GDP	0.501*** [0.0926]
REEL	0.0978** [0.0462]
CPIE	0.0113*** [0.0035]
PRI	0.5163*** [0.2956]

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own estimation from the data obtained from the given sources.

Table 6. Robustness (AMG test).

Variable(s)	Coefficients
GDP	0.511***
REEL	0.166***
CPIE	0.012***
PRI	0.014***
Constant	−5.677***

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own estimation from the data obtained from the given sources.

Table 7. Dumitrescu-Hurlin causality test.

Null hypothesis:	W-Stat.	Zbar-Stat.	Prob.
GDP – ENEF	3.8281***	4.477	0.000
ENEF – GDP	4.6866***	4.640	0.000
REEL – ENEF	4.7251***	5.938	0.000
ENEF – REEL	3.9013***	4.596	0.000
CPIE – ENEF	2.3352**	2.045	0.040
ENEF – CPIE	5.5672***	4.793	0.000
PRI – ENEF	6.9479***	5.414	0.000
ENEF – PRI	7.2859***	5.335	0.000

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own estimation from the data obtained from the given sources.

variables have a positive and significant impact on E.N.E.F. in the long run. Specifically, enhancement in G.D.P., R.E.E.L., C.P.I.E., and P.R.I. enhance E.N.E.F. by 0.501, 0.0978, 0.0113 and 0.5163%. The results are highly statistically significant at 1%, 5%, and 10% levels for the variables mentioned. As the channel of influence is already discussed in the C.S.-A.R.D.L. discussion, the estimated results are consistent to the empirical results of Zakari et al. (2022) for economic growth, Kolosok et al. (2021) for renewable energy, Valizadeh et al. (2018) for energy related inflation, and Wang et al. (2022) for political risk.

Once the study obtained the short- and long-run estimates, the authors further test the long-run elasticities for each variable under consideration for robustness of the model. In this sense, the study uses the A.M.G. estimator and the empirical results are given in Table 6. From the empirical outcomes, this study noted that all the variables exhibit positive and statistically significant influence on E.N.E.F. Although the magnitude value in this test is different than the previous estimators. Still the direction of the influence as well as the significance level remained the same, which validates the empirical findings of both C.S.-A.R.D.L. and D.C.C.E.-G.M.M. approaches.

After achieving the long- and short-run estimates, this study observed that the earlier specifications lacks to reveal the causal influence of each variable under consideration. In this sense, the current study employs the Dumitrescu-Hurlin heterogenous Granger causality test and the empirical results are reported in Table 7. The estimated results unveil that there exist a bidirectional causal association between the E.N.E.F. and the explanatory variables such as G.D.P., R.E.E.L., C.P.I.E. and P.R.I. The estimated outcomes are highly significant at 1% and 5% levels. Thus, this study reports that all the mentioned variables could play a substantial part in construction and promoting E.N.E.F. related policy implications. Where improvements in E.N.E.F. that are cost-effective may have beneficial macroeconomic effects, enhancing economic activity and frequently contributing to employment creation. E.N.E.F. minimises the amount of energy used to provide services such as transportation, heating, lighting and air conditioning.

5. Conclusion and policy implications

In this contemporary times, economies across the globe is taking various steps and actions to maintain or even recover environmental quality. Therefore, various policies have been constructed and implemented, which are yet vital in reducing environmental issues. Among others, E.N.E.F. promotion is one of the main policy to reduce extensive energy utilisation in the country. In this respect, there are several factors that could influence E.N.E.F. This study explores whether economic growth, renewable energy, energy related prices and political risk have impact on E.N.E.F. in the developed economies. Using various panel data approaches, this study observed that economic growth, renewable energy, energy related prices and political risk are the significant factors of E.N.E.F. in the G7 economies. Specifically, the economic growth enhances the investment level in E.N.E.F. sector, where industries tends to reduce the production cost. Additionally, increase the prices of energy tends to reduce demand for the industrial sector, due to which the industrial sector employs energy efficient machinery and equipment, and also transfers to renewable energy sector, to obtained the same level of output by utilising lesser energy. Due to political risk, the investors hesitate in investing into the energy sector, due to which the energy prices are unstable and the industrial sector as well as other economic activities are severely affected. To overcome such adverse impact in the industrial sector, they tends to enhance E.N.E.F., which needs lesser energy for maintaining the industrial output and economic performance.

Based on the empirical results, this study suggest policies that could be advantageous for the scholars and policy-makers in the developed region. Firstly, this study recommends policies regarding the encouragement of industrial sector, which contributes to the economic progress, and enhances investment in the E.N.E.F. sector. Secondly, developed economies should enhance investment in renewable energy sector, which itself not only leads to environmental sustainability, but also leads to enhance E.N.E.F. measures. Hence, in order to improve E.N.E.F., renewable energy sector shall also be improved. Nonetheless, increase in energy prices reduce demand for traditional energy consumption, which could also affect the industrial sector and other economic activities. Therefore, this study suggested authorities to intervene by increasing the prices of energy, while subsidising those industries that are using energy efficient machinery, equipment, and resources. Lastly, this study suggest the G7 economies to increase investment in the research and development sector related to E.N.E.F. This measure will not only reduce energy demand and cost of production, but also enhance economic and environmental sustainability.

Although this study covers important factors and indicators of E.N.E.F. Still, this study is limited in few directions, which are suggested for the future researchers. That is, this study considers only the four factors that are affecting E.N.E.F. in the G7 economies. However, there are other variables, such as financial (financial development, green finance, financial inclusion), environmental (environmental policy stringency, carbon emission, natural resources extraction), trade, technological innovation, research and development indicators that could also influence E.N.E.F. Therefore, the future researcher are directed to empirically analyse the relationship of these variables with E.N.E.F. Besides, this study only covers the panel of developed economies, while ignoring the emerging and under-developed economies. Therefore, there this study directs the future researchers and scholars to extend this study for the mentioned group of economies. Moreover, the data unavailability issue restricts this study to analyse only the last three decades. However, after the availability of the data, the future researchers could use the extended dataset to extensively analyse the circumstances via more advanced econometric approaches.

Notes

1. For data, visit: https://www.prsgroup.com/
2. For data, visit: https://stats.oecd.org/
3. For data, visit: https://databank.worldbank.org/source/world-development-indicators

Disclosure statement

No potential conflict of interest was reported by the author.

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