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Corruption and renewable energy consumption in 42 developed countries: A pooled mean group analysis

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The substantial increase in global renewable energy usage has promoted research in this field, particularly in developed countries, which play a crucial role in reducing the impacts of climate change. However, the role and effects of corruption on this type of energy have attracted less attention. Moreover, as attention to the link between corruption and renewable energy are critical criteria for development, it is imperative to assess the link between corruption and renewable energy, especially in developed countries, where they claim to have succeeded in the fight against corruption. This study examines the relation between corruption and renewable energy usage in 42 developed nations. The analysis employs the pooled mean group technique and covers the period between 2012–2020. Results reveal a strong and meaningful relation between the corruption perception index and renewable energy consumption in the long term, while it is insignificant in the short term. Based on these results, we suggest that policymakers should focus on the environmental effects of corruption and on implementing effective policies.

Keywords: renewable energy consumption, corruption, pooled mean group

Corruption is a phenomenon that has a negative impact on the proper functioning of markets and reduces economic development and optimal allocation of resources *(Korani et al., 2022)*. Corruption reflects a set of illegal activities that threaten the functioning of economies, the climate quality and the environmental subjects *(Leitão, 2021)* and spreads quickly *(Sundström, 2013)*. Renewable energy is an essential policy. Renewable sources, such as wind and solar, have developed rapidly in recent years and have been encouraged by public support programmes that promote low-carbon energy options.

Grossman and Krueger (1995) reported that corruption has a threshold effect on the environment. Corruption can lead to less environmental degradation at some income levels and higher at others. When there is corruption in the public sector, renewable energy may not effectively reduce carbon emissions and afford the best results. However, previous studies *(Balsalobre-Lorente et al., 2021)* on the environmental Kuznets curve have not examined the impact of corruption on climate change, leaving a gap in the literature on the effects of corruption on renewable energy consumption. There are two notable contributions of this study to the literature. (I) Corruption, economic growth, urban population and renewable energy are integrated, for the first time, into an analytical framework. As such, this study provides an important reference for considering the inner penetration system of corruption and renewable energy consumption. (II) This study uses the pooled mean group (PMG) approach (an effective method) for analysing the short- and long-term relations between corruption and renewable energy consumption.

Present study examined the relation between renewable energy, corruption perceptions, economic growth and urban population using panel data on developed countries from 2012 to 2020. First, the authors present an overview of the literature based on the relation between renewable energy, perceptions of corruption, economic growth and urban population. Second, applications of the econometric model assess the short- and long-term relations between the variables. The results show whether renewable energy consumption creates opportunities for rent-seeking and corrupt practices when public motivations make the production of renewable energy profitable. This study tested the hypothesis that corruption in developed countries significantly affects renewable energy consumption in 42 countries in the period from2012 to 2020. The relations are tested using the PMG approach.

1. Theory of corruption

Corruption remains a concern worldwide (*Goel and Nelson*, 2010). Corruption is an act when public agencies use their power to gain private profits by changing the rules of the game *(Jain, 2001)*. It has also been defined by *Transparency International (2020)*, which developed one of the most widely used corruption indices as the misuse of power for personal benefits. Corruption is the abuse of a privilege offered by public sector occupations or is generally defined as the misuse of public resources for personal gain. Most studies identified corruption as a

phenomenon with adverse effects, although some positive effects have been found, especially in underdeveloped or transition countries *(Korani et al., 2021)*. In addition, not only formal public sector activities but also the actions of nongovernmental authorities can be corrupt *(Klitgaard*, *1988)*. Owing to the convolution of identifying corruption, which results from its nature, international regulatory authorities have designed country ranking indices *(Zhang et al., 2016)*. Reducing corruption and its impacts requires an understanding of its causes *(Dong et al., 2012)*. Therefore, the economic literature deals with the determinants of corruption and reasons that corruption level is based on the equilibrium between the corruption-related costs and gains arising from it.

In developed countries, corruption has decreased to levels where the possibility of continued decline does not exist because the institutional costs to decrease corruption are more than the gains. Thus, environmental quality does not considerably affect corruption and another mechanism might be required to reduce pollution levels. *Zhang et al. (2021)* showed that renewable energy consumption is a phenomenon that involves the demand and supply sides and corporate governance and the rule of law can significantly regulate the energy market. *Lazaro et al. (2021)* conducted an interesting qualitative study to examine politics and government dynamics using a biofuel case study. They demonstrated how government support aids better biofuel management. *Putnam and Brown (2021)* proposed a fiscal system and social governance for reinforcement loans and energy poverty plans to improve environmental fairness, improve the energy equity situation and support constructing a better system for accepting renewable energy. Most studies highlighted the role of governance in renewable and non-renewable energy consumption and social instruments, including corruption control, political stability and the rule of law.

2. Literature review

Salim and Shafiei (2014) analysed the effects of urbanisation on renewable and non-renewable energy consumption in the organization for economic cooperation and development countries from 1980 to 2011 using the stochastic impacts by regression on population, affluence and technology model. The results showed that total population and urbanisation positively affect non-renewable energy consumption and population density adversely affects non-renewable energy

consumption. They reported that, among the demographic factors, only the total population has significantly affected renewable energy consumption.

Saidi and Mbarek (2016) examined the effects of clean energy consumption, carbon dioxide (CO_2) emissions, renewable energy and economic growth in nine developed countries. These findings showed that renewable energy consumption was an essential factor for the long-term economic growth of countries. Thus, implementing stern energy policies is an efficient means of economic growth.

Sinha et al. (2018) evaluated corrupt practices hindering renewable energy growth implementation in eleven selected countries. They reported that corruption has different effects on fossil fuels and renewable energy. The authors were the first to analyse the effects of corruption on environmental deterioration, separating energy sources into fossil fuel and renewable energy. Finally, corruption occurs when there is a less stringent energy policy.

In a case study, *Dogmus and Nielsen (2020)* investigated corruption in the hydropower sector in Bosnia and Herzegovina, a transitional developing country. They reported that the bureaucratic process of tenders, procurement and hydropower projects created a secure environment for corrupt stagers, including the government and private sectors, which resulted in incomplete projects.

Uzar (2020a) examined the effects of income inequality on renewable energy consumption in 43 developed and developing countries and found how corruption control has a positive effect on renewable energy consumption and that governments can invest existing resources in renewable energy projects.

Leitão (2021) studied the relations between economic growth, corruption, renewable energy, international trade and CO_2 emissions using panel data on European countries from 1995 to 2015. The study used the panel fully modified least squares, panel dynamic least squares and a panel two-stage least squares estimator as an econometric approach. The findings showed how economic growth and the corruption index trend have a significant positive effect on CO_2 emissions, but renewable energy and international trade advance environmental quality and lessen climate change.

Mahmood et al. (2021) explored the impact of economic growth and various governance indices on non-renewable and renewable energy consumption using data on South Asian countries, from 1996 to 2019. The authors used several econometric methods to discover the long-term impacts. The results showed that corruption control has positive effects on natural gas consumption. Stable policies adversely affect non-renewable energy consumption and positively the renewable energy one. The measure of the effects of economic growth and most governance indices were greater for non-renewable resources than renewable resources.

Ren et al. (2021) examined the relation between government corruption, market segmentation and renewable energy technology innovation. They reported that

governmental corruption can increase the grade of market segmentation, and both corruption and market segmentation can degrade territorial renewable energy technology innovation. Analyses indicate how improved market segmentation can lead to a negative corruption effect on renewable energy technology innovation. Rising corruption level can increase the impacts of negative market segmentation on renewable energy technology innovation. Furthermore, higher market segmentation measure can escalate the effect of corruption on renewable energy technology innovation.

Wang and Yang (2021) focused on the relation between corruption control, renewable energy and carbon emission reduction using panel data on 98 countries, from 1996 to 2015. As the mediation model is estimated by multiplex regression equations, the total, direct and indirect impacts can be isolated in order to elucidate the guidance route between carbon emissions, renewable energy and corruption control. The results show that renewable energy is a considerable intermediary that corruption controls and contributes to emission reduction through it.

3. Methodology

The authors used the PMG approach suggested by *Pesaran et al. (1999)* in present study, an effective error correction method for describing short- and long-term relations *(Uzar, 2020a)*. The PMG estimators presume that explanatory variables can be considered exogenous, and there is a long-term relation between explanatory and dependent variables *(Lee–Wang, 2015)*. Unlike the mean group estimator, which uses the average coefficient value for each country and presumes that the error variance and slope of coefficients are the same for each country, the PMG estimator assumes that the long-term coefficient is homogeneous for each country and, by contrast, the short-term coefficient and error variance are heterogeneous *(Uzar, 2020b)*. *Da Silva et al. (2018)* expressed how the PMG approach is more appropriate than other panel data methods, such as the generalised method of moment estimators, instrumental variables and fixed effects. Unless the coefficients are the same among countries, these methods can result in contradictory estimates. The PMG method produces firm and effective estimators and dispels endogeneity problems by including the lag length of the variables *(Uzar, 2020b)*. Using the panel model explained by *Sydney et al. (2021)*, renewable energy consumption (*REN*) is considered the dependent variable and depicted in Equation (1):

$$\boldsymbol{lnREN_{it} = a_i + \beta lnCPI_{it} + \gamma lnGDPP_{it} + \delta lnUPOP_{it} + v_i + \epsilon_{it}} \quad (1)$$

The model is described in a natural logarithmic form. The estimated coefficients can be interpreted as elasticities when all variables are stated in natural logarithms. The sub-index i and t refer to countries and the period, respectively, i.e., 2012–2020. REN denotes renewable energy consumption; GDPP denotes the per capita gross domestic product (GDPP); corruption perceptions index (CPI) denotes the CPI, where a high index indicates a low level of corruption; UPOP denotes the urban population. The disturbances ε_{it} are distributed over time and units, with zero mean and constant variance per unit.

Two second-generation panel unit root tests, cross-sectional dependence (CD) test and cross-section correlations of the residuals in augmented Dickey–Fuller (ADF) (*p*) regressions were used to specify the merger degree of the respective variables. *Pesaran's (2007)* panel unit root test does not require the estimation of factor load to dispel CD. The usual ADF regression was augmented to contain the lagged cross-sectional mean and its first difference to capture the CD results in a single-factor model. The existence of co-integration in a heterogeneous panel context was examined using the methodological approach of *Pedroni (2004)*. Modelling was performed using recently developed techniques for heterogeneous panels robust to co-integration and CD *(Pesaran–Tosetti*, *2011)*. *Levin et al. (2002)* suggested a panel unit root test based on the ADF test. The Pedroni test was performed for the long-term estimates because each variable contained a panel unit root.

A balanced panel data set of nine years (2012–2020 inclusive) and 42 developed countries was used because of data availability for these countries in the Transparency International database. Renewable energy consumption is the share of renewable energy in total energy consumption. GDPP is the sum of gross value added by producers in the economy divided by the population. The data were from the World Bank Data Indicators *(WDI, 2020)*, and the CPIs were extracted from the *Transparency International (2020)*. The variables were standardised using their natural logarithmic forms to overcome heteroscedasticity. The specification was then subjected to panel unit root test, Pedroni tests and model estimation using the PMG approach. The econometric analysis tool EViews 12 software was used for the estimation methods.

4. Results

This section presents the econometric results to test the relation between renewable energy consumption, corruption perceptions, economic growth and urban population.

Table 1 lists the descriptive statistics for the selected 42 countries.

Table 1

Descriptive statistics for the selected countries

	REN	GDPP	CPI	POP
Mean	24.905	34996.25	68.337	20210913
Maximum	87.320	118823.6	92.000	2.72E+08
Minimum	2.680	722.8943	42.000	47790.00
Std. Dev.	19.304	24909.01	12.451	44357698

Table 2 lists the results of the CD test, showing that the heterogeneous panels are robust to co-integration and CD.

Table 2

Results of the CD test

Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	3188.790	861	0.000
Pesaran scaled LM	56.095		0.000
Pesaran CD	20.403		0.000

Table 3 lists the unit root test results using the methodology of Levin, Lin and Chu; ADF–Fisher Chi-square; Phillips–Perron; Im–Pesaran–Shin. These results show that the variables of renewable energy consumption (*LRENEW*), economic growth (*LGDPP*), CPI (*LCPI*) and urban population (*LUPOP*) are stationary at the first difference I (1).

Table 3

Unit root test results

	Ln RENEW	Ln GDPP	Ln CPI	Ln POP
Level 0				
Levin, Lin& Chu t*	–5.142**	–12.137**	–8.528**	–8.103**
Im, Pesaran and Shin W-stat	1.847	–2.895**	–0.771	0.187
ADF – Fisher Chi-square	69.410	126.879**	99.868	124.259**
PP – Fisher Chi-square	115.679**	80.501	142.222**	255.714**
Level 1				
Levin, Lin& Chu t*	–55.154**	–17.099**	–7.119**	–3.841**
Im, Pesaran and Shin W-stat	–11.874**	–3.263**	–2.259**	–0.241
ADF – Fisher Chi-square	206.011**	141.986**	121.113**	108.168**
PP – Fisher Chi-square	325.427**	137.990**	285.593**	97.028

Note: Critical value is at the 5% level, significance denoted by (**).

The Pedroni test statistics with the null hypothesis showing no co-integration for all units in the panel. The test statistic reported in Table 4 showed strong evidence that all units in the model are co-integrated. This result shows that the long-term estimates in all countries based on the PMG approach are robust *(Uzar, 2020a)*.

Table 4

Pedroni test results with intercept

Alternative hypothesis: common AR coefs. (Within-dimension)				
	Statistic	Prob.	Weighted statistic	Prob.
Panel v-statistic	–2.4039	0.9929	–3.955	1.000
Panel rho-statistic	4.798	1.000	2.905	0.998
Panel PP-statistic	–3.229**	0.001	–12.983**	0.000
Panel ADF-statistic	–6.8239**	0.000	–7.523**	0.000
Group rho-statistic	5.913	1.000		
Group PP-statistic	–15.039**	0.000		
Group ADF-statistic	–7.992**	0.000		

Note: Critical value is at the 5% level, significance denoted by (**).

Table 5 lists the long-term results for the countries. All coefficients were statistically significant at the 0.05 levels in the PMG method. The coefficient of GDPP had a negative impact. The statistical significance of per capita economic growth suggests that economic growth decreases with renewable energy consumption. According to the PMG estimates, a 1% increase in economic growth decreases renewable energy consumption by 0.25%. Urban population has a positive effect on renewable energy consumption. Furthermore, a 1% increase in CPI increases renewable energy consumption by 1.12%, while a 1% increase in urban population increases renewable energy consumption by 0.64%.

Table 5

Long-term PMG estimation ARDL (1, 1, 1, 1)

Variable	Coefficient	Std. error z-statistic	z-statistic p -value	p -value
LGDPP	–0.25**	0.026	–9.563	0.000
LCPI	1.12**	0.0459	24.363	0.000
LUPOP	0.64**	0.003	219.958	0.000

Note: ***, ** represent statistically significant at 10%, 5% levels.

Table 6 lists the short-term results for the countries. All the coefficients were statistically insignificant at the 0.05 and 0.1 levels, except for the urban population in the PMG method in the short term. The error correction term was between −1 and 0 and statistically significant at the 5% level. This suggests a convergence of

the balance level in the short term (*Uzar, 2020a*). The error correction term was −0.93. The estimated regression of renewable energy consumption functions fitted the data well, with more than 98% of the variation in renewable energy consumption described by the PMG method. The coefficient of the urban population had a positive effect on renewable energy consumption. The statistical significance excluded the suggestion that urban population decreased as renewable energy consumption increased. According to the PMG estimates, a 1% increase in urban population increased renewable energy consumption by 69.53%. The coefficients of CPI and GDPP are insignificant.

Table 6

Short-term PMG estimation ARDL (1, 1, 1, 1)

Variable	Coefficient	Std. error z-statistic	z-statistic p -value	p -value
COINTEQ01	–0.93**	0.361	–2.571	0.011
D(LGDPP)	0.09	0.143	0.649	0.518
D(LCPI)	–0.34	0.308	–0.994	0.322
D(LUPOP)	69.53***	39.754	1.749	0.083
C	–7.53**	2.302	–3.272	0.001
@TREND	–0.01	0.023	–0.505	0.615

Note: ***, ** represent statistically significant at 10%, 5% levels.

The result shows how CPI positively impacts long-term renewable energy consumption. Similarly, *Mahmood et al. (2021)*, *Ren et al. (2021)* and *Uzar (2020a)* reported that decreasing corruption positively affects renewable energy consumption. Reduction of corruption strengthens the endeavour of government authorities to boost public interest. *Arminen and Menegaki (2019)* reported that corruption is an obstacle in implementing environmental regulation. Therefore, reducing corruption should increase renewable energy consumption. Similarly, political stability positively affects renewable energy consumption, as reported by *Leitão (2021)*. Thus, a stable policy allows the government to install renewable energy capacities, which take a long time to install and replace non-renewable energy. Hence, developed countries should promulgate political stability indices to reinforce renewable energy for environmental sustainability. As a first step, anti-corruption policies are essential for achieving growth in renewable energy consumption.

In the short term, the coefficient of economic growth is insignificant. The result showed that GDPP adversely affects long-term renewable energy consumption. *Uzar (2020a)* acknowledged that the relation between renewable energy consumption and per capita GDP could be vague after detecting an insignificant negative relation between GDP per capita and renewable energy. *Leitão (2021)* suggested that economic growth has a statistically significant and positive effect

on CO_2 emissions. Hence, GDPP has a positive effect on non-renewable energy consumption. By contrast, *Kilinc-Ata (2016)* and *Shahbaz et al. (2015)* reported how income measures, such as per capita GDP, have a positive impact on renewable energy consumption in developed countries. In addition, *Saidi and Mbarek (2016)* reported that renewable energy consumption is a crucial component of the long-term economic growth of countries.

Results suggest that urban population growth increases renewable energy consumption. By contrast, *Salim and Shafiei (2014)* demonstrated that the urban population does not significantly impact renewable energy consumption. The positive relation between population and energy use is reported in some prior studies *(Poumanyvong–Kaneko, 2010; Poumanyvong et al., 2012)*.

5. Conclusion

This study investigates the effects of corruption perception, economic growth and urban population on renewable energy consumption using panel data from 2012 to 2020, focusing on 42 developed countries. The hypotheses were tested using the panel unit root test. Results show that the variables used in this study are stationary in the first difference I(1). In addition, the Pedroni test shows that renewable energy consumption, economic growth, CPI and urban population are co-integrated in the long term. The model used was PMG.

In the short term, the coefficient of CPI is insignificant. Results indicate that CPI has positive effects on long-term renewable energy consumption. The statistically significant effect of CPI on developed countries at the 5% level underscores the need to develop effective mechanisms to reduce the level of corruption to reach sustainable development. reducing the level of corruption is also necessary for various economic activities and the implementation of renewable energy technologies. The main policy implication of this study is as follows: corruption in countries leads to more pollution. By reducing corruption, developed countries can considerably modify the circumstances for renewable energy development. *Dogmus and Nielsen (2020)* showed that sophisticated bureaucratic processes lead to a secure environment for corruption stagers, resulting in unfinished projects. The existence of corruption slows renewable energy execution processes down. The rent-seeking behaviour of public bodies is an obstacle in the renewable energy implementation process. *Fredriksson and Svensson (2003)* showed that corruption increases the number of bribes and affects

environmental bureaucrats, making environmental policies less strict. Countries with consistent regulative frames in renewable energy benefit the most from the value generated by this sector.

Governments should establish independent regulatory bodies to review renewable energy solution projects in developed countries. These regulatory bodies could decrease the level of corruption by influencing the interest rate of loans for energy projects. This will ensure that distribution partners for renewable energy generation and distribution systems have to pay less, encouraging the pursuit of renewable energy solutions. Privatisation measures of the energy market in state-controlled utilities must be pursued to promote the required efficiency and ensure accountability. Stability and accountability in supporting institutions in energy markets can attract new investments in renewables. In addition, policymakers must consider raising citizens' awareness, (a) educational plans can be designed based on the motivation of sustainable development of these countries, (b) the profits of renewable energy and energy efficiency can be realised and (c) corrupt actions can be controlled locally.

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