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Article

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Dynamic Common Correlated Effects of Public Debt on Energy Poverty Alleviation in OIC Member Countries: Does Institutional Performance Matter?

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Abstract

Extensive literature explored debt-growth, growth-energy usage, and growth-poverty link. However, the debt and energy poverty (EP) has received less focus. Despite having a significant impact of these two on economic performance and millions of people's lives. This study employs a modern sets of econometrics approach to resolve the cross-sectional dependency (CSD) and heterogeneity influence of debt on EP alleviation and also explore the moderating role of institutional quality (IQ) from 2000 to 2017 in developing countries of Organization of Islamic Cooperation (OIC). Energy poverty alleviation index is obtained by recruiting four different indicators of energy poverty. We employ dynamic common correlated effect estimator introduced by Chudik and Pesaran (2015) that is suitable in case of cross-sectional dependence and slope heterogeneity. Long run outcomes of the study disclose nonlinear association between public debt and EP alleviation indicating that public debt is conducive for EP reduction up to certain level, but after that, any additional public debt hurts the energy poverty alleviation. Results of the interaction term of the study show that IQ strongly impacts the effect of public debt. On the base of empirical outcomes, it is recommended that public debt should be maintained at a certain level and also the developing countries of OIC should strength their institutional efficiency as it enhances the

EP alleviation. This is the novel study that investigates properly the role of institutional performance in debt-energy poverty link in OIC developing countries.

Keywords: public debt, energy poverty, institutional quality, dynamic common correlated effects, OIC countries.

1. Introduction

In 2015 the global community develops a consensus on 17-points of Sustainable Development Goals (SDGs). The seventh goal concerned with the availability of clean and affordable energy because it plays a vibrant role in human development (Selçuk et al., 2019; Wang et al., 2021), augmenting productivity (Sohag et al., 2021), promoting economic performance (Ivanovski et al., 2021), and backing in poverty reduction (Zhao et al., 2022). However, in developing nations, increasing trend in energy price, fiscal imbalances, withdrawal of subsidies, and limited access to modern fuels have aggravated the energy poverty (Awan & Bilgili, 2022). If people have no access to safe and inexpensive energy sources, they are said to be energy poor. Globally, one billion people are experiencing energy poverty (IEA, 2019), which is characterized by low energy consumption, the usage of unclean fuels, and they are spending too much time by getting fuel to fulfil their fundamental necessities.

Currently, the world is confronting EP, energy supply security, and global warming (González-Eguino, 2015). Among these issues, less attention is paid to EP than other. In this investigation, we examine how IQ and public debt (PD) affect EP. The idea of EP became popular in 1970s during the oil crisis (Primc et al., 2021). In literature EP has been defined in numerous ways. For example, Hills (2011) and Moore (2012) agree that EP is attributed to energy prices, income, and energy efficiency whereas, Churchill and Smyth (2021) think that EP describes a household's failure to maintain an acceptable degree of heating. Significantly, these definitions are relevant only to developed nations. According to research, EP in developing nations seems to be more severe than in developed nations (Zhao et al., 2021). The IEA (2002) described concept of EP in developing economies. It was noted that household living in energy poverty are those who heavy rely on conventional biomass energy because they have lack access to clean fuels. EP arises when a sizable portion of a consumer's income goes toward their energy costs, making it difficult for them to pay other payments (Winkler et al., 2011).

Prior studies on EP identified a number of influencing factors like changes in policy, household income and consumption, socio-economic features of household, income poverty & energy policy (Crentsil et al., 2019; Mendoza Jr et al., 2019; Sharma et al., 2019). The technology-oriented aspects of EP have also been the subject of several earlier research. For example, Fabbri (2015) suggests a fuel poverty index to assess problems associated to fuel poverty. Solar energy projects tend to have a conducive role in EP alleviation in the rural area of China (Liu et al., 2021). More recent evidence has centered

on the macroeconomic factors that determined EP. For example, using a panel data set of thirty developing countries Apergis et al., (2022) disclosed that human capital alleviates EP. Bilateral trade does not assist in overcoming EP (Zhao et al., 2022). Halkos and Gkampoura (2021) asserted that problems with energy poverty are negatively correlated with economic performance. Albeit a little consideration has been given to unravelling the influence of public debt on EP from OIC developing nations. Hence, this study is motivated by the suggesting note of Churchill and Smyth (2021) that additional research should be done to unveil number of potential drivers of EP alleviation.

After the global fiscal crisis and Covid-19 outbreak, public debt gained momentum and interest in the economic literature. Extensive empirical literature explored debt-growth link and ended up with mixed outcomes (Salmon, 2021). Literature documented a nonlinear threshold level of public debt after that it thwarted the economic growth (Law et al., 2021). The relationship between public debt and economic expansion has follow an inverted U-shaped pattern (Kassouri et al., 2021). Specifically, in Keynesian school of thoughts an increase in public debt augments the economic growth due to the mechanism of expenditure multiplier (Auerbach & Gorodnichenko, 2012). Nevertheless, excessive public debt may have a detriment influence on economic performance due to its crowding out effect (Modigliani, 1961; Diamond, 1965). As a results, it may infer that PD have a nonlinear influence on EP. Furthermore, good institutional quality (IQ) acts as a catalyst of public debt. It is hypothesized that good IQ may matter the debt-energy poverty link through the resourceful and prudent use of PD. As the literature validated that threshold value of debt is higher for nations with better institutional quality (Law et al., 2021).

We specifically focus on following research objectives. The very first objective of the study looks at how public debt affects energy poverty. We explicitly examine the possibility that public debt on energy has nonlinear consequences. Second, the research seeks to investigate how institutional quality impact energy poverty. Third, the study discovers that IQ has a crucial role in determining how public debt on EP is affected. Public debt makes a significant contribution to reducing EP in nations with superior IQ. This work also adds to the literature by checking the threshold point of marginal effect of public debt at different level of IQ. The outcome is anticipated to have policy implications for establishing the best course of action to reduce energy poverty through institutional quality and public debt. Fourth, we employ a novel technique created by Chudik and Pesaran (2015) for the period of 2000 to 2017 in OIC developing nations. This methodology is innovative because it considers the heterogeneity and structural break problems in panel data that are frequent and neglected by other approaches. Fifth, we did panel causality to unveil the causal link between the model's variables and also for the robust analysis this study employs two-step GMM. Sixth, the findings ought to motivate decision-makers to develop fiscal strategies that are more successful, particularly with regard to raising institutional standards and choosing an appropriate level of public debt. To perform empirical investigations a group of twenty-five developing economies of OIC is selected, four proxies are recruited for EP alleviation index. OIC has fifty-seven member countries

with Islamic background and is the least explored area in term of debt-growth, growth-environment, and debt-energy poverty relationships.

The remaining study is tailored in the following fashion, glimpse of literature survey and hypothesis development are elucidated in section two, data and methodology are calibrated in section three, panel empirics are portraited and debated in section four. The concluding remarks and policy proposal are the part of closing section.

2. Literature Review and Development of Hypothesis

2.1 Measurement of Energy Poverty (EP)

To measures EP, different researchers and organization developed different indicators which are unidimensional indicators, dashboard indicators and composite indices (see, Sy & Mokaddem, 2022). The single dimensional element of EP is considered by the single indicators. "The dashboard indicators are a group of non-aggregated measures that provide a comprehensive view of a nation's energy system to measures and track the achievement of SDGs (Iddrisu & Bhattacharyya, 2015). To overcome the shortcomings of the single and dashboard indicators, the multidimensional index is a frequently used as a tool of EP measurement (Nussbaumer, et al., 2012; Iddrisu & Bhattacharyya, 2015). It is based on the creation of a single index by combining various energy indicators. Moreover, single dimensional has three approaches: economic physical, and technological approach (Pachauri & Spreng, 2011). Economic approach used maximum percentage of household income or expenditure to identify the EP level, the physical approach puts more emphasis on basic energy services that a family need and the technological approach deals with people's lack of access to modern energy services. González-Eguino (2015) went on to say that albeit all three strategies are complementary however each have drawbacks. For instance, the economic approach has trouble in comparing temperatures between different nations due to differences in power prices and purchasing power, the physical approach has trouble in defining what constitutes a "basic energy services, and the third approach lacks information on income-level energy consumption.

The empirical evidence also combats this ongoing rise in EP by employing several energy poverty measurements in accordance with the facts that are available. To proceed further to review literature on EP measurements we review only those studies which used single dimension measure for EP. More precisely, the singular index technique was devised by Boardman (1991), who said that a household was deemed to be energy poor if its energy spending exceeded 10% of its earnings. In India, Pachauri et al. (2004) provided a brand-new indication with two dimensions of EP that considered both how people got their energy and how much they used. Buzar (2007) used the number of houses with inadequate heating as a measure for EP. Access to electricity was employed as a gauge of EP in studies on Brazil and Ghana by Pereira et al. (2010) and Obeng et al. (2008), respectively. Parajuli (2011) used the availability of modern cooking technology to assess the level of EP in

Nepal. In Bangladesh and Australia, respectively, Barnes et al. (2011); Chester and Morris (2011) identified the the threshold where rising household income causes energy usage to increase. In a plethora of recent empirical studies, for example in case of Greece, Papada and Kaliampakos (2016) used the ratio of actual energy spending to family income before taxes to define the level of EP. In sample of Spain during 2004-2015, Aristondo and Onaindia (2018) used three energy accessibility measure to gauge EP (i) keeping the house warm enough, (ii) the arrears on utility bills like electricity, water, and gas (iii) and the appearance of leaky roofs, moist walls, or rotten windows. Similarly, Halkos and Gkampoura (2021) in panel setting of Europe Union economies used the same measures for EP. Churchill and Smyth (2021) used access to clean fuels and modern technologies for cooking, or access to electricity reliable indicators of EP. Sharma et al. (2019) used electricity expenditure as a proxy for EP in India. Wang et al. (2021) used a threshold at 10% of a household's annual gross income for energy expenditures as proxy for EP in the sample of United States. Apergis et al. (2022) in thirty developing economies employed many proxies to capture the various facets of energy poverty.

There are also some recent studies that used a composite index as a measure for EP. For instance, Mendoza Jr et al. (2019) in Philippines created a composite index of multidimensional household EP by employing seven measures of EP. Awan and Bilgili (2022) chose two distinct metrics of EP, namely 10% and double median derived from using HIES survey (Household Income and Expenditure Survey) data compiled between 1998 and 2019 in Pakistan. Zhao et al. (2022) in a panel set of sixty-four countries developed a composite index for EP. Wang et al. (2015) established an index to measure EP in developing nations. Dong et al. (2021) and Zhao et al. (2021) also employed this measure to reassess EP in China, and they reached the same conclusion. It is also evident that EP is a problem in both advanced and growing economies, but it varies depending on the situation (Sadath & Acharya, 2017). However, the lack of access to modern sources of energy, which are required to deliver contemporary energy services, is characterized as EP in emerging economies. (Lin & Wang, 2020). It can be attributed to a lack of infrastructure, efficient marketplaces for energy services, and enough money to pay for modern energy sources (Tarekegne, 2020). However, in any scenario, there is a general consensus that there is no general approach exist which can be employed to evaluate EP (Zhao et al., 2022).

2.2 Public Debt and Energy Poverty

Different studies deciphered the role of several factors in EP. For instance, Pereira et al. (2010) explored the impact of electrification program, Chester and Morris (2011), Okushima (2016) the rising energy costs, demographic variables by Crentsil et al. (2019, consumption expenditure in India by Sharma et al. (2019), Apergis et al., (2022) explored the role of education, in a sample of Turkey financial inclusion by Dogan et al. (2021). Nguyen and Su (2022), and Dimnwobi et al, (2022) unveiled the effect of government spending on energy poverty. Acheampong et al. (2022) income inequality, governance, and

Che et al. (2023) used financial outlay and employment in a sample of China. More of this there is no empirical study available which documented the role of public debt in EP. Whereas public debt is a significant factor affecting economic growth, which in turn is a key driver in the eradication of EP.

Theoretically, public debt has a positive, negative, neutral, and nonlinear impact on economic growth and also the empirical literature reveals conflicting results about debt-growth relationship (Saungweme & Odhiambo 2018). According to nonlinear or threshold approach, the connection between PD and economic growth is favorable at lower levels and negative at greater levels (Reinhart & Rogoff, 2010). Numerous studies, particularly those conducted in developing nations, have revealed this non-linear link (Law et al., 2021). According to the empirical literature, impact of PD on economic performance follows an inverted U shape pattern (Kassouri et al., 2021). Notably, in small size government, a rise in PD may be advantageous for output due to crowding in effect and a high level of PD may thwart the economic performance due to crowding out effect (Aurangzaib & Farooq, 2022). As a result, the inverted-U influence of PD on economic growth may also contribute to a U impact of PD on EP. The first hypothesis proposed by this study is the following.

- **H_1:** Public debt has nonlinear impact on EP alleviation (inverted U-shaped curve) in OIC developing countries.

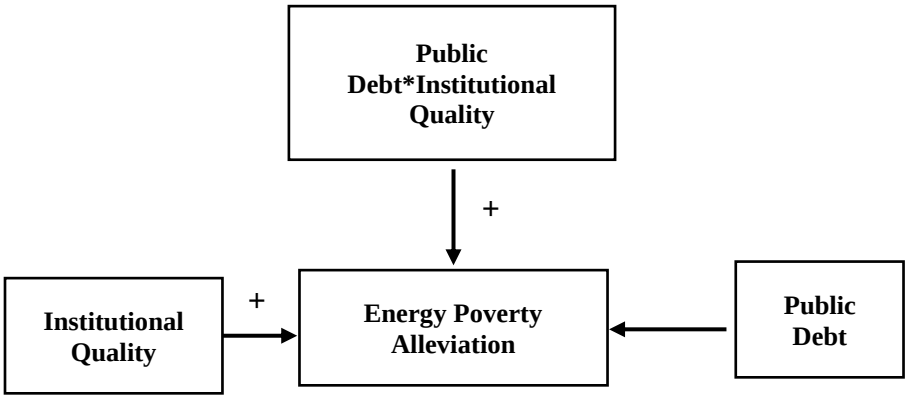

Figure 1: Conceptual Framework of the Study

2.3 Institutional Quality and EP

To accelerate the EP reduction clean energy source and technologies play a vibrant role (Bhide & Monroy, 2011). In China, government adopt the transition energy policy from polluting energy source to clean energy as a tool to lessen EP (Liu & Li, 2011). By increasing renewable energy resources, decreasing the cost of energy make people to afford renewable energy and use less conventional biofuel this help in reduction the EP (Dong et

al., 2021). To build sufficient clean and affordable energy reserves which lead to decrease in energy price and EP, proper institutional measures like government stability, bureaucratic quality, law and order, control of corruption and democracy are needed because as renewable energy is considered a more expensive than traditional fossil fuels, proactive measures to encourage clean energy may necessitate a robust institutional structure (Mehrara, 2015). Sequeira and Santos (2018), Uzar (2020) documented a positive role of IQ in clean energy usage. In this regard, institutional quality may have a direct impact on investments in clean energy sources, which may result to a decline in EP in OIC countries.

- **H_2:** Institutional quality has significant positive impact on EP alleviation in OIC developing countries.

The literature on public debt places a strong emphasis on the crucial part that institutions play in the efficiency of debt management (Melecky, 2012). Institutions govern society as a whole and impose restrictions on economic agents (North, 1990; Acemoglu & Robinson, 2008). It is possible to claim that strong IQ would enable the adoption of laws that support the effective use of public debt in productive investment, such as infrastructure that can drive economic growth and employment. Furthermore, effective institutions may lessen uncertainty for the private sector by allocating funds to improving the infrastructure and business climate that would encourage private investment and spur economic progress. Consequently, having a higher IQ increases the effectiveness of public debt (Law et al., 2021; Aurangzaib & Farooq, 2022), which in turn increases the sound effects of PD on addressing EP. In light of this, we hypothesize that IQ moderates the connection between PD and EP alleviation. Therefore, to quantify the combine impact of public debt on EP alleviation via the channel of IQ we frame the third hypothesis. The conceptual outline of the study is described in figure one.

- **H_3:** Institutional quality significantly moderates the impact of PD on EP alleviation in OIC developing countries.

3. Data and Methodology

3.1 Empirical Specification

According to the literature (e.g., Hills, 2011; Moore, 2012), the basic function of EP alleviation is as follow:

$$EP = f(Y, EE) \quad (1)$$

Then, as an additional factor influencing EP alleviation, public debt (PD) is incorporated as follows:

$$EP = f(Y, EE, PD) \quad (2)$$

Based on the above models, the following empirical equation is developed. To lessen the likelihood of autocorrelation and heteroscedasticity, all the data transformed into natural

logarithms (Bekhet and Othman (2017). Also, we employ the dynamic panel for estimation in order to fully account the lag effect of EP.

$$EP_{it} = \gamma_0 + \gamma_1 EP_{it-1} + \gamma_2 Y_{it} + \gamma_3 EE_{it} + \gamma_4 PD_{it} + \nu_{it} \quad (3)$$

The above model, N has 25, denoted by i, estimated over T = 18 years, and indicated by t, whereas γ is the coefficient to be estimated; ν is the error term. To decipher the effect of PD on EP alleviation, Eq. 3 is formulated then to empirical test the hypothesis [H1] we incorporate the PD^2 in Eq. 3. Also, to empirical test the hypothesis [H2] we incorporate the institutional quality (IQ) variable in the model. Furthermore, to envisage the moderating impact of IQ on EP alleviation with respect to PD, we incorporate an interaction term in Eq. 3 and tailor the following equation to empirical test the hypothesis [H3] and others.

$$EP_{it} = \gamma_0 + \gamma_1 EP_{it-1} + \gamma_2 Y_{it} + \gamma_3 EE_{it} + \gamma_4 PD_{it} + \gamma_5 PD^2_{it} + \gamma_6 IQ_{it} + \gamma_7 (PD_{it} * IQ_{it}) + \nu_{it} \quad (4)$$

From Eq. 4 we get the subsequent specification with reference to hypothesis [H1], if $\gamma_5 < 0$ and $\gamma_6 > 0$ then u-shaped association prevail between public debt and EP alleviation. If $\gamma_5 > 0$ and $\gamma_6 < 0$ then there is inverted u-shaped public debt and EP alleviation relationship exist. To numerically measure the marginal impact of interaction term to find the real effect and turning point at mean, maximum and minimum level of IQ therefore, we take partial derivative of the eq. 4 with respect to PD without its square term.

$$\frac{\delta EP_{it}}{\delta PD_{it}} = \gamma_4 + \gamma_7 IQ_{it} \quad (5)$$

3.2 Data Source and Variables Selection

Annual data from 2000 to 2017 is used for 25 OIC developing nations remaining OIC nations are excluded due to lack of data (countries' list available in supplement table A1). This study uses central government debt as a proportion of GDP (PD), collected from IMF. We use five proxies of institutional measures like government stability, corruption, quality of bureaucracy, law and order and democratic accountability, we use ICRG database and rescale all measures from 0 to 10 then employ PCA command to construct a composite index of IQ, real GDP per capita income is deemed as a proxy for economic growth (Y) and collected from WDI. Energy use per unit of gross domestic product (GDP/kg oil equivalent) is used for energy efficiency (EE). which has a substantial effect on EP. The expected sign of the coefficients value of Y, EE, IQ, PD and (PD*IQ) are positive and PD^2 having a negative expected sign.

This study uses technological approach to measure EP and recruit four different proxies related to EP alleviation to develop an index (EPI) by following the work of Churchill et al. (2020) and Churchill and Smyth (2021) we choose access to clean fuels and technologies for cooking along with the three other measures regarding the accessibility of electricity: access to electricity for the entire population, urban population, and rural

population as main variables for the EP alleviation index and collected from WDI. It is important to mention that increase in the value of EPI refer to a reduction in EP. It is worth mentioning that the selection of theses proxies is in consonance with the definition of EP (González-Eguino (2015).

3.3 Econometrics Strategy

We open our study with the cross-sectional dependence test (CSD) as there are numerous social, economic, and cultural connections that connect nations and may induce spillover effects. For this reason, the analysis recruits the Pesaran (2004) CD and Pesaran-Scaled LM and Biased-adjusted LM test. After the validation of CSD, we proceed to verify the existence of slope heterogeneity among the cross-section units. The heterogeneous concern is vital to resolve since there is a potential of heterogeneity in slope parameters owing to variation in the demographic and economic structure of OIC developing countries, which may raise significant questions on the consistency of panel estimators. Therefore, this study employs the slope homogeneity method proposed by Pesaran and Yamagata (2008). To investigate the stationarity properties of the chosen variables we proceed with second generation unit root test established by Pesaran (2007). This approach works well, especially in the presence of CSD and slope heterogeneity. We also used Westerlund (2007), ECM-based cointegration approach to examine the long-term relationships between the designed model variables. This test delivers unbiased results in the presence of heterogeneity and CSD, which makes it unique to traditional cointegration approaches like Kao and Pedroni. Next, we use the dynamic common correlated effect (DCCE) developed by Chudik and Pesaran (2015) to decipher the long-run and short-run connections between EP, Income, Energy Efficiency, PD, and institutional quality in developing nations of OIC. The DCCE generates trustworthy results since it is resilient to endogeneity and non-stationarity concerns, as well as to cross-sectional dependence and heterogeneity challenges (Chaudhary et al., 2021). The study employs DCCE approach by recruiting Jackknife command in STATA for robust standard error and robust variance as it is very advantageous for the small sample size (Chudik & Pesaran, 2015). Also, this study develops two econometric models, in model one nonlinear impact of public debt is investigated and model two explored the moderating role of IQ on EP alleviation. The below is a hypothesized empirical model for DCCE estimator.

Additionally, we continue with the system GMM (S-GMM) created by Arellano and Bover (1995) and Blundell and Bond (1998) for robustness analysis by using the xtabond2 command in STATA by (Roodman, 2009), which permits us to tackle the CSD and heterogeneity issue. Albeit DCCE and S-GMM findings offer useful interface, but they do not provide direction of association between variables which may be key for policy ramifications. This study considered Dumitrescu and Hurlin (2012) approach to observe the causal connection between the variables.

4. Data Analysis and Discussions

In table 1, descriptive and correlation statistics of the variables are presented. LNEPI, LNPD, LNIQ, LNY, LNEE, LNPD*IQ are used for an index of energy poverty alleviation, public debt, institutional quality index, real income per capita constant 2010 US$, energy efficiency and the interaction term between PD and IQ respectively. All variables are in natural logarithm form. The mean value of LNEPI is 1.457 while maximum and minimum values are 2.047 and -2.896 respectively. Mean values of LNPD, LNIQ, LNY, LNEE and LNPD*IQ are 3.487, 0.758, 7.586, 2.617 and 4.244 respectively. LNEPI, LNPD and LNIQ, LNEE and interaction term are negative skewedness, and all have a leptokurtosis except LNEE. On the hand LNY have positive skewness value with platykurtic distribution. The lower part of the table 1 presenting the correlation matrix of the variables.

Table 1: Data Descriptions and Correlation Matrix of All Variables

	LNEPI	**LNPD**	**LNIQ**	**LNY**	**LNEE**	**LNPD*IQ**
Mean	1.457	3.487	0.758	7.586	2.617	4.244
Median	1.744	3.603	0.863	7.594	3.290	4.405
Maximum	2.047	4.931	1.651	9.614	4.485	6.264
Minimum	-2.896	0.216	-4.575	5.669	-2.813	-1.202
Std. Dev.	0.768	0.872	0.660	0.941	1.676	1.163
Skew.	-2.674	-1.177	-3.758	0.146	-0.779	-1.138
Kurtosis	11.822	4.829	26.941	2.030	2.532	5.248
Obs.	450	450	450	450	450	450
LNEPI	1.000	0.391	0.533	0.854	-0.488	0.682
LNPD		1.000	0.214	-0.060	0.052	0.957
LNIQ			1.000	0.353	0.310	0.214
LY				1.000	-0.245	0.360
LNEE					1.000	0.052
LNPD*IQ						1.000

Table 2: Cross-Section Dependence

Variable	Pesaran-Scaled LM	Pesaran-CD	Bias-Adjusted Scale LM
LNEPI	106.20* (0.000)	45.15* (0.000)	105.46* (0.000)
LNPD	82.53* (0.000)	34.79 * (0.000)	81.79* (0.000)
$LNPD^2$	82.53* (0.000)	34.79 * (0.000)	81.79* (0.000)
LNIQ	48.64* (0.000)	21.55* (0.000)	47.91* (0.000)
LNY	123.57* (0.000)	35.84* (0.000)	122.84* (0.000)
LNEE	42.31* (0.000)	43.61* (0.000)	42.87* (0.000)
LN(PD*IQ)	83.48* (0.000)	38.51* (0.000)	82.74* (0.000)

Probability in parentheses and * display a significance level at 1%.

To proceed further with empirics' estimation, we did different cross sectional dependency test like Pesaran scaled LM, Pesaran CD and bias-adjusted scaled LM test. In the era of globalization countries are interlinked and no country is isolated. So, to proceed with panel data ignoring the countries dependency may lead to inconsistent outcomes. The outcomes of CSD (Cross-sectional dependency) are presenting in table 2. The findings of the CSD are also important in deciding whether we proceed with first generation unit root test which suppose no cross-sectional dependency or with second generation unit root test. In our case there is straightforward evidence of rejection of null hypothesis of cross-sectional independency. The slope homogeneity results displayed in table 3 are also corroborating the presence of slope heterogeneity in coefficient by applying the test of Pesaran and Yamagata (2008).

Table 3: Slope Homogeneity Outcomes

Model	Delta	Adjusted Delta
Model 1	2.794*	3.840*
Model 2	2.722*	3.740*

* Indicates a 1% level of significance

Table 4: Outcomes of Second-Generation Unit Root Test

	CIPS		CADF		Decision
Variables	**Level**	**Difference**	**Level**	**Difference**	
LNEPI	-1.632	-5.055*	-1.864	-5.055*	I(1)
LNPD	-1.689	-3.579*	-1.689	-3.579*	I(1)
$LNPD^2$	-1.689	-3.579*	-1.689	-3.579*	I(1)
LNIQ	-1.859	-2.973*	-0.733	-6.604*	I(1)
LNY	-1.374	-3.177*	-1.374	-3.177*	I(1)
LNEE	-1.076	-4.258*	-1.567	-4.258*	I(1)
LN(PD*IQ)	-2.068	-3.659*	-1.946	-3.659*	I(1)

* Display a 1% and 10% level of significance

Therefore, we apply second generation unit root test like CIPS and CADF by following Pesaran (2007), and empirics are portraited in table 4. The outcomes unveil that all variables are stationary at first difference, and no one is exposed to be stationary at second difference. To envisage the long run association among the variables, this study recruits the Westerlund (2007), a second generation cointegration test which is preferable over the first generation cointegration test which may produce misleading outcome in the presence of autocorrelation, heteroscedasticity, structural break and CSD (Chaudhary et al., 2021). The portraited outcomes in table 5 show a clear indication of long run association in our case. Also, the error correction parameters $\delta = P\alpha/T = -3.678/18 = -0.21$ for model one and -0.27 for model two. These outcomes imply that 27% error between EPI and its determining factor will be corrected each year. As a result, any short-term disequilibrium is eliminated in the long-term models.

Table 5: WesterLund Panel Co-Integration Outcomes H_0: no cointegration

Stat	Model-1 (Probability)	Model-2 (Probability)
G_τ	-4.83* (0.000)	-4.887* (0.000)
G_α	-4.11 (1.000)	-5.150 (1.000)
P_τ	-16.93* (0.001)	-17.078* (0.004)
P_α	-3.678 (1.000)	-4.907 (1.000)

* Indicate 1% significance level

After concluding the cointegration evaluation and others, we proceed further and employ DCCE method to determine the long-run and short-run elasticities. Table 6 displays the

results of the DCCE estimator. In model 1, the coefficient values of LNY (Real GDP per capita) are significantly positive, indicating that LNY enhances EP alleviation. In the short run, a 1% increase in real GDP per capita results in an average 0.305% improvement in EP alleviation. Additionally, a similar increase in income over the long term causes a 0.253% increase in EP alleviation. The economic interpretation of this positive relationship can be expressed that economic growth alleviates the EP by investing in energy infrastructure and expand access to electricity to underdeveloped areas. Economic growth can also attract private investment in energy sector, which can lead to the development of new power generation projects and the expansion of the existing ones which in turns help in EP. These findings are in line with the prior studies of Apergis et al, (2021); Acheampong,et al, (2022); Nguyen and Su (2022). The findings of the study also validate the Energy Ladder Hypothesis posits that as income of the household increase, they will upgrade their energy consumption from traditional to modern sources, reducing EP. The impact of energy efficiency on energy poverty alleviation is positive and statistically significant at 10% in both short run and long run. A one percent increase in energy efficiency will lessen a 0.02% EP in short run and 0.031% in long run. By improving energy efficiency can lower energy usage per unit of output value and successfully minimize the wastage of finite resources, thus helps to fight against energy poverty. These findings are endorsed by the previous studies of (Apergis et al., 2022; Zhao et al., 2022).

Regarding the impact of PD and IQ on EP alleviation which is our novel contribution to the empirical literature of energy poverty. For this we develop two model, in model one we empirical test the nonlinear impact of public debt on EP alleviation. While on the other side to response the research hypothesis formulated in section 2, will an increased in public debt impact EP alleviation by improving the performance of institutions? To empirical answer this research hypothesis this study chooses the interaction term in model two which shows the estimates of linear impact of public debt and also the moderating role of institutional performance on EP alleviation. Short run outcomes show that there is nonlinear impact present, but it is not statistically significant even at a 10% level of significance. In long run, coefficient value of square term of PD indicates that 1% increase in PD debt augment the energy poverty by 0.022%. In model one the coefficient sign of public debt is positive while the sign of square term is opposite which is clear indication of nonlinear connection between PD and EP alleviation which validate our hypothesis [H1] of nonlinear connection of PD on EP alleviation in OIC developing economies. It elucidates how the energy poverty of OIC developing countries might worsen if a certain level of public debt is reached. A plausible explanation of this nonlinear connection is the non-linear link between PD and economic growth which in turn may hurt the EP alleviation process in developing nations. The following studies e.g., Ndoricimpa, (2020); Kassouri et al. (2021); Law et al., (2021); Aurangzaib and Farooq (2022) have documented the nonlinear effect of PD on economic progress in developing countries. Also, the study of Nguyen and Su backed these findings that public spending reduce EP until a certain level and after that it hurts the EP reduction. Concerning the impact of institutional quality, the

coefficient value is statistically positive at 5% in short run and at 1% in long run of model one. A 0.061% decrease in energy poverty is due to institutional performance in short run and also a 0.218% alleviation in EP is due to institutional quality in long run. The elasticity of EP with respect to institutional quality is robust in long run as compared to short run. The findings of the model two unveils that institutional performance doesn't play its moderating role in short run while in long run the institutional quality moderate the adverse impact of public debt on EP alleviation. The plausible explanation of these findings may be that in short run institutions are not well functioning that they utilize the borrowed funds in EP programs. The findings are in line with Acemoglu et al., (2001; 2005) that weak institutions are the real root cause of poverty and underdevelopment. On contrary, the long run coefficient sign of the interaction term is positive which show that institutions effectively use public debt to reduce EP. The reasons seem to be that in long run robust institutions create policies and regulatory framework that ensure transparency and accountability that ensure the borrowed funds are utilized for the intended purpose which is to finance energy poverty alleviation programs. These findings are consistent with the conclusions of Ahlborg et al, (2015) and Acheampong et al, (2022). The long run findings of the study corroborate our two and three hypotheses.

Table 6: Estimation of Dynamic Common Correlate Effect (DCCE)

	Regressors	Model 1 (Main effect)	Model 2 (Moderating Effect)
Short Run Estimates	d.LNY	0.305*	0.393*
		(0.068)	(0.052)
	d.LNEE	0.020***	0.021***
		(0.011)	(0.011)
	d.LNPD	0.178	-0.235
		(0. 118)	(0.157)
	$d.LNPD^2$	-0.004	--------
		(0.003)	--------
	d.LNIQ	0.061**	0.065**
		(0.027)	(0.026)
	d.LN(PD*IQ)	--------	-0.040**
		--------	(0.018)
Long Run Estimates	l.LNEPI	-0.887*	-0.781*
		(0.197)	(0.172)
	l.LNY	0.253*	0.272*
		(0.054)	(0.047)
	l.LNEE	0.031***	0.028***
		(0.018)	(0.015)
	l.LNPD	0.825*	-0.346*
		(0.076)	(0.049)
	$l.LNPD^2$	-0.022**	-------
		(0.009)	-------
	l.LNIQ	0.218*	0.243*
		(0.054)	(0.047)
	l.LN(PD*IQ)	--------	0.278*
		--------	(0.027)

Standard errors in parentheses, *, **, *** display level of significance at 1%, 5% and 10% respectively

Another novel contribution to the empirical literature of energy poverty alleviation is that this study calculates the marginal impact of interaction term which indicates the actual impact and tipping point at maximum, minimum and mean level of institutional performance in this regard we use the Eq. 5 and obtain the corresponding outcomes, presented in table 7. Public debt on energy poverty alleviation at maximum. Minimum and average level of institutional quality. $\frac{\delta EP_{it}}{\delta PD_{it}} = -0.235 + 0.278IQ_{it}$

Table 7: Marginal Effect

		Minimum	Mean	Maximum
Developing countries of OIC	Institutional Quality	-4.575	0.758	1.651
	Marginal effect	-4.532	-0.024	0.224

The marginal effect of public debt on energy poverty alleviation at minimum, average and maximum level of IQ is -4.532, -0.024 and 0.244 respectively. The constant term of marginal effect is -0.235 and the coefficient value is 0.278 respectively. The groundbreaking findings reveal that higher levels of institutional quality in OIC developing nations reduce the negative effects of public debt on EP. It is also important to note that institutional quality doesn't ameliorate the detrimental impact of PD on EP alleviation in short run estimation. However, the long-term results demonstrate that institutional quality has a remarkable moderating effect in reducing the adverse impression of PD on the reduction of energy poverty. It is also crucial to highlight that institutional quality in OIC developing countries plays a mediating effect at the maximum level rather than the lowest or the average level because institutional performance in these countries is typically not up to the high standard level (Arvin et al., 2021; Boateng et al., 2021; Law et al., 2021). The robustness of the findings is also examined by employing the System GMM estimator which corroborate the outcomes of the DCCE estimator. The corresponding findings of the robustness analysis are documented in table 8.

Table: 8 Robustness Analysis (System GMM)

Short Run and Long Run Estimates

	Regressors	**Model 1 (Main effect)**	**Model 2 (Moderating Effect)**
Short Run Estimates	l.LEPI	-0.806*	-0.911*
		(0.041)	(0.035)
	d.LNY	0.235*	0.262*
		(0.051)	(0.047)
	d.LNEE	0.075	0.073
		(0.072)	(0.069)
	d.LNPD	0.176	-0.254
		(0.116)	(0.168)
	$d.LNPD^2$	-0.009	------
		(0.007)	------
	d.LNIQ	0.049*	0.039**
		(0.021)	(0.018)
	d.LN(PD*IQ)	------	-0.053**
		------	(0.025)
	Constant	-0.706**	-0.409**
		(0.323)	(0.187)
Diagnostic Stat	Obs.	425	425
	Cross sections	25	25
	J	20	20
	AR1	-1.618	-1.651
	p-value AR1	0.106	0.098
	AR2	0.959	1.042
	p-value AR2	0.337	0.297
	Hansen	16.15	16.17
	p-value Hansen	0.304	0.303

	LR Estimates		
Long Run Estimates	l.LNY	0.203*	0.254*
		(0.046)	(0.039)
	l.LNEE	0.012	0.013***
		(0.008)	(0.008)
	l.LNPD	0.797*	-0.383*
		(0.064)	(0.057)
	$l.LNPD^2$	-0.026*	--------
		(0.012)	--------
	l.LNIQ	0.193*	0.201*
		(0.048)	(0.045)
	l.LN(PD*IQ)	--------	0.491*
		--------	(0.047)

Standard errors in parentheses,
*, **, *** display level of significance at 1%, 5% and 10% respectively
For long run outcomes, nlcom command is used in STATA

Next, to assess the causal connection between public debt, income, energy efficiency, IQ, and EP alleviation, we recruit the panel causality test established by Dumitrescu and Hurlin (2012) and the corresponding findings are presented in table 9. The study's results indicate that there are several causal relationships in empirical analysis, pointing to the feedback hypothesis that there is a bidirectional causal connection between PD and EP alleviation (EPA), institutional quality to EPA, real per capita income to EPA, energy efficiency to EPA, real per capita income to public debt and a unidirectional causality is documented between EPA to interaction term of public debt and institutional quality and also between institutional quality and interaction term.

Table 9: Outcomes of Dumitrescu and Hurlin Panel Causality Test

Null Hypothesis	W-Stat	Ẃbar-Stat	Prob	Remarks
PD → EPI	5.7468	16.7824*	(0.0000)	Bidirectional Causality
EPI → PD	2.0814	2.43116**	(0.0151)	
IQ → EPI	3.3360	8.2590*	(0.0000)	Bidirectional Causality
EPA→IQ	2.1290	2.55779**	(0.0105)	
Y → EPI	7.6400	23.4761*	(0.0001)	Bidirectional Causality
EPI → Y	2.1647	4.1179*	(0.0000)	
EE → EPI	2.7123	6.0538*	(0.0000)	Bidirectional Causality
EPI → EE	3.1233	7.5070*	(0.0000)	
PDIQ → EPI	10.8031	34.6592*	(0.0000)	Bidirectional Causality
EPI → PDIQ	1.9627	3.4037*	(0.0000)	
IQ → PD	1.7475	1.54388	(0.1226)	Unidirectional Causality
PD → IQ	1.7131	2.5212**	(0.0117)	
Y → PD	3.9863	10.5581*	(0.0000)	Bidirectional Causality
PD → Y	4.5984	12.7222*	(0.0000)	
EE → PD	2.8237	6.4476*	(0.0000)	Bidirectional Causality
PD → EE	6.1871	18.3391*	(0.0000)	
PDIQ → PD	1.7513	2.6562*	(0.0079)	Bidirectional Causality
PD → PDIQ	2.1145	3.9403*	(0.0000)	
IQ → PDIQ	2.0176	3.5976*	(0.0000)	Unidirectional Causality
PDIQ → IQ	1.6359	1.2471	(0.2124)	
Y → PDIQ	2.8933	6.6937*	(0.0000)	Bidirectional Causality
PDIQ → Y	3.9860	10.5572*	(0.0000)	
EE → PDIQ	2.5284	5.4037*	(0.0000)	Bidirectional Causality
PDIQ → EE	3.5891	9.1540*	(0.0000)	

Note: *, * display 1% and 5% level of significance, also → designates "doesn't granger cause

5. Conclusion and Policy Suggestions

This study looks into the implications of public debt on the reduction of EP by developing an index of energy poverty alleviation in a panel of 25 OIC developing nations from 200 to 2018. The study employs four empirical investigations by utilizing the more recent

econometrics approach known as dynamic common correlated effects (DCCE). First, estimates are made of the linear and nonlinear impact of PD on EP alleviation. The study also reflects the impact of IQ on reducing energy poverty. Thirdly, the study presents how effect of public debt on energy poverty alleviation depends on institutional quality. Finally, the study assesses the marginal impact of the public on reducing EP at various institutional quality levels. According to the estimations, the square of public debt (expressed as a percentage of GDP) significantly hinders EP relief. This mean that up to a certain point, rising public debt augments EP relief. Any additional rise in the public debt after this level would undermine efforts to reduce the EP. In other words, the impact of public debt on reducing EP in OIC developing economies is inverted U-shaped. This study most likely establishes the debt Laffer curve theory's relationship with energy economics and energy poverty for the first time. More explicitly, this inverted U shape relationship originate from the debt-growth relationship, as debt augments growth which in turn reduce EP, as debt reduce the growth which in turn thwart the EP alleviation, this conclusion is also backed by the Energy Ladder Hypothesis. Further, these conclusions demonstrate that the government can use public debt to reduce energy poverty, but only up to a certain point; if public debt is too high, its beneficial effects will actually have the reversed effect on reducing energy poverty. Moreover, we also deciphered the moderating role of IQ on PD and EP alleviation. Our conclusions regarding the interaction term show that better institutional efficiency mitigates the detrimental impact of public debt on EP at a particular institutional level. Also, EP alleviation continues to benefit from other traditional factors like real income per capita and energy efficiency.

Based on conclusions of the study the following policies are suggested. First, Authorities should use caution when implementing their fiscal policies. Public debt shouldn’t be increased specifically without a cap, as excessive public debt would worsen the energy poverty crisis. To lessen the detrimental consequences of high public debt on energy poverty, the debt ceiling should be incorporated into the debt management strategy. This approach is not only advantageous for economic growth but also for the reduction of energy poverty. Secondly, it is observed that determinants of institutional quality like government stability, corruption, quality of bureaucracy, law and order and accountability of democratic institutions augment the EP alleviation. Developing countries of OIC should upgraded IQ up to the high standard so that it can better moderate any detrimental consequence of PD on EP.

There are fifty-seven OIC countries however due to the non-availability of data only 25 OIC member countries are taken which limits the study. In addition, this study offers a future study guideline, increase the sample size by including the global economies and then divide the sample into Low-income and High-income subsamples so that it would give a fuller view of the debt-energy poverty nexus at various levels of institutional performance.

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Appendix

Table A1: List of OIC Countries

Albania	Gabon	Morocco	Togo
Algeria	Gambia	Mozambique	Tunisia
Azerbaijan	Indonesia	Niger	Turkey
Bangladesh	Iran	Nigeria	Yemen
Cameroon	Jordon	Pakistan	
Côte d'Ivoire	Kazakhstan	Senegal	
Egypt	Mali	Sudan	