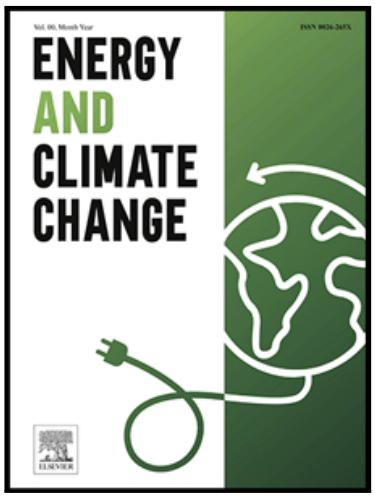
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Securing energy while mitigating climate change

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Highlights

- One of the first studies binding energy security and climate change mitigation and accomplishes it by econometrics.
- Electricity generation by solar and wind helps both securing energy and climate change mitigation as anticipated.
- Coal-based power generation does not contribute to global energy security unlike mainstream energy policy advocates.
- Increasing energy intensity, i.e., decreasing energy efficiency releases more carbon as anticipated. However, increasing energy intensity, i.e., decreasing energy efficiency, contributes to energy security of the countries with wind power in the energy mix.
- Having a large population promotes energy security but increasing urban population brings risks.

Securing energy while mitigating climate change

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Abstract

Mainstream energy policy emphasizes the exploitation of domestic sources to secure energy. Since readily available, many nations focus on fossil fuels, so they lack investment in alternatives. The result is increasing atmospheric partial pressure of carbon dioxide, and energy security is still an issue. This study analyzes the impact of different variables on securing energy and reducing carbon emissions and attains this aim by econometrics. Energy-related data for 47 countries have been compiled from the IEA webpage, WDI, and BP databases, covering the period between 1990 and 2017. The results indicate that electricity generation by solar and wind globally helps both securing energy and climate change mitigation as anticipated. The dataset confirms that coal- and gas-based power generation does not contribute to global energy security. The dataset does not cast any distinct role on energy efficiency in terms of energy intensity. Increasing energy intensity, i.e., decreasing energy efficiency releases more carbon as anticipated. However, increasing energy intensity, i.e., decreasing energy efficiency, contributes to the energy security of the countries with wind power in the energy mix. One interesting result is that having a large population promotes energy security, but increasing urban population brings risks.

Keywords

Energy Policy, Energy Security, Climate Change Mitigation, Electricity, Panel Data Econometrics

ABBREVIATIONS

ASEAN, Association of Southeast Asian Nations; BP, British Petroleum; BRICS, Brazil, Russia, India, China, South Africa; CCPP, Combined Cycle Power Plant; CCS, Carbon Capture and Sequestration; CTP, Coal Thermal Power; EU, European Union; GDP, Gross Domestic Product; GHG, Greenhouse Gas; GTP, Gas Thermal Power; IEA, International Energy Agency; IPCC, Intergovernmental Panel for Climate Change; KTOE, Kilo tons oil equivalent; LM, Lower-mid

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income; MTOE, Million tons oil equivalent; NPP, Nuclear Power Plant; OECD, Organization for Economic Cooperation and Development; PV, Photovoltaic; SP, Solar Power; TWh, Tera watt hours; US, United States; WDI, World Development Indicators database of the World Bank Group; WP, Wind Power

1. Introduction

Energy enables individuals to exceed their physical limitations and achieve things that would not be possible otherwise. The uneven distribution of fossil fuels makes energy a "strategic commodity". Therefore, assuring energy security is one of the prime goals of public policy since, like the environment, it is a public good, which brings invaluable benefits for both private persons and societies [1],[2]. Contemporary energy policies are to consider all energy sources and a wide variety of risks ranging from natural to political. In that sense, energy policies need a scrupulous and wide analysis of energy security [3]. There are two key issues for global energy security: meeting growing global demand in the long-run and managing volatile energy, specifically oil, prices. Global rising demand is mainly a problem because of the rapid development of countries like China and India. This requires continuous investment in resources and infrastructure and puts more stress on sources and competition among nations, both importing and exporting. Price volatility is considered a threat to economic growth and will have varying impacts on citizens and countries based on their income levels. In other words, high dependence on energy systems requires understanding the risks and prerequisites for energy security, and it is different from only energy supply since it needs consideration of the integrity of the whole chain from field to final consumer [4].

Technology, energy security, and sustainability are shaping electricity generation. It was first in 2019 that electricity generated from nuclear power and renewables was more than from coal. Renewables are expected to overtake coal power plants in 2025. Solar PV alone is estimated to supply 30% of global electricity by 2030 [5]. Security of electricity supply with all its components became an issue along with supply security of energy sources [6], and prices [1]. Regarding electricity, the problem is related with generation rather than depletion as in fossil fuels. Supply at any time must meet demand, specifically peak demand. Thus, the major risk for electricity supply security is a lack of investment in generation and transmission since electricity cannot be stored efficiently [7].

Besides technological constraints, sustainability is another challenge for the electricity sector. All forms of energy use create environmental problems. In today's world, the most challenging issue is climate change. Climate change is a long-term alteration in the average weather events in local, regional, and global climates. Changes observed since the beginning of the 20th century are specifically the result of fossil fuel consumption by humans [8] and are estimated to cause more than 1℃ of global warming compared to pre-industrial averages. If the current rate of warming continues, the expectation is 1.5℃ increase between 2030 and 2052. Projected impacts vary according to regions but include heavy precipitations, extreme droughts, sea level rise due to melting of glaciers, and loss of habitats and biodiversity [9] and resulting economic, social, and political impacts on human welfare. In other words, being a vital component of the Earth System, changing climates not only compel physically but also beget upheavals in the anthroposphere, spreading to every component of it, including energy systems and security.

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Concerns on climate change have also brought attempts to link the issue with energy security, but mainstream energy security discussions and policies fail to grasp it as an integral part of the issue because the main focus is energy independence [10]. Climate change and energy security are interdependent and multifaceted. Any action or measure to reduce emissions in one way or another will have an impact on fuel mix and technology and thus influence energy supply and security. On the other hand, measures aiming at energy security will again influence domestic energy mix and technology, altering emissions and contributing to climate change. For instance, increasing the share of renewables to lower emissions is expected to increase energy security via domestic sources, or increasing share of domestic fossil fuels to secure energy will amplify climate change [11]. Similarly, changing precipitation regimes alters the availability of water for hydropower plants, increasing temperatures reduce the efficiency of solar panels, frequent extreme events damage windmills, or a severe drought forces people to migrate, which may increase energy demand in the destination land. On the other hand, policies on climate change may delay the depletion of fossil resources and reduce energy imports as well as demand technology transition [12]–[15]. In short, there is not any policy measure that addresses both climate change and energy security although options such as efficiency, conservation, and clean technology are beneficial for both. Focusing on one might worsen the other, thus, the balance should be established [14].

In light of the above discussion, the main objective of this study is to assess the role of coal, gas, wind, and solar in electricity supply security and climate change mitigation, which is the main contribution. In other words, this study couples two different research areas: climate change mitigation and energy security. The countries included in the analyses are OECD, EU, ASEAN, and BRICS. The study employs econometric methods to find answers to the questions it poses. Cross-country panel data analyses are conducted to estimate parameters causing carbon dioxide emissions due to electricity generation and energy dependency with selected explanatory variables.

2. Literature Review

As [16] points out, energy security is analyzed with various indicators related to the concept that the issue is addressed. The majority of the studies deal with energy security performance over time and compare the countries, and mainly is measuring diversity in electricity supply via Herfindahl-Hirschman or Shannon-Wiener indexes and the indicators chosen vary from dimension to dimension. However, such indexing fails to provide reliable results to measure the energy security performance of the countries [17]. Therefore, a reliable method that enables policymakers to assess whether their country is on track toward energy security is required, and econometric analysis is a strong alternative to fill this gap. Econometrics is gaining attention in energy security literature. [18] analyzes energy security strategies that affect renewable energy deployment within 21 EU member states via panel econometrics. It states that renewable deployment is a consequence of different energy security strategies, and diversification is the main driver. [19] focuses on 28 EU countries to understand the impact of fossil fuel prices on energy security. The panel data analysis shows that energy security is mainly influenced by year. Gas price has more impact compared to the other fossil prices. [20] analyzes wind power

investments in 17 African countries. Panel data analysis shows that energy security is one of the main reasons for interest in wind power. [21] investigates the impact of urbanization on energy security through energy intensity and reveals a reinforcing impact. Panel data of 72 countries show that urbanization increases energy intensity. Questioning the influence of oil prices, [22] also investigates renewable investments in African countries with energy security concerns. The study shows that increasing oil prices augment investments in renewables in the countries which aim for energy security. The studies referred to mainly question the contribution of energy security to renewable deployment. [23] focuses on 23 OECD countries and analyzes the impact of renewable energy sources on energy security. Panel data techniques show that hydropower, wind, and total renewable contribute to energy security, whereas solar and biomass do not have a significant effect. Similar to [23], our study aims to understand the contribution of different energy/power sources to energy security.

Unlike energy security, econometrics has been used to identify the relationship between GHG emissions and electricity generation. [24] focuses on ASEAN countries. Using a panel vector error correction for five countries, the study confirms positive relationship between electricity consumption and CO_2 emissions. Using a dynamic panel data model, [25] investigates CO_2 determinants for 69 countries. There is a positive relationship between electricity consumption per capita and carbon emissions. [26] explores the impact of electricity consumption on CO_2 emissions in 14 sub-Saharan countries. Panel cointegration and panel vector error correction models reveal a reinforcing relationship. Similarly, [27] shows a positive relationship between electricity consumption and CO_2 emissions for 10 Middle East and North African countries via panel Fully Modified Ordinary Least Squares and Dynamic Ordinary Least Squares. [28] uses fixed-effect panel econometrics to analyze 48 U.S. states to test the impact of clean energy policies on carbon emissions. The results indicate that supply-side energy policies help reduction of carbon emissions in the electricity sector. By dynamic ordinary least square estimator for the EU, [29] states that renewable energy sources contribute to climate change mitigation while non-renewable fuel sources augment carbon emissions. [30] uses a panel of 93 countries to estimate the contribution of renewable sources to CO_2 reduction and states that a 1% increase in non-fossil-based electricity generation results in 0.82% less CO_2 per capita. Through an econometric model for 5 EU countries, [31] analyzes CO_2 reduction by renewable electricity consumption. The study shows a negative relationship between these two variables. With many econometric techniques [32] estimates a reinforcing relationship between carbon emissions and electricity consumption in Türkiye. [33] focuses on China's electricity sector. The econometric model used in the study estimates a positive relationship between CO_2 emissions and electricity generation in China. Similarly, our study focuses on electricity generation but is concerned with the contribution of each energy/power source widely used to climate change mitigation.

3. Data and Methodology

3.1. Model

The following models are used to estimate the effect on carbon dioxide emissions and energy imports.

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$$lnCO2_{it} = \beta_{0i} + \sum_{j=1}^{j} \beta_j X_{jt} + \sum_{k=1}^{k} \beta_k D_{kt} + \mu_{it} \quad (1)$$

$$lnEI_{it} = \beta_{0i} + \sum_{j=1}^{j} \beta_j X_{jt} + \sum_{k=1}^{k} \beta_k D_{kt} + \mu_{it} \quad (2)$$

, where X represents independent variables, D represents dummy variables, β represents parameters to be estimated, and μ represents error term.

3.2. Data

Data for all countries and geographic divisions are downloaded from the WDI database. Countries not members of EU, OECD, BRICS, or ASEAN are eliminated, and the remaining are cleaned off missing observations. After cleaning, 47 countries are left (see Table C- 1). To obtain the most up-to-date data available, IEAIEA and BP databases are also used. The final dataset contains data from three databases: WDI, BP, and IEA. WDI provides energy-related data for 1960 – 2015 with gaps in cross-sections and time series. BP provides data for years after 2015 but has fewer cross-sections than WDI. Moreover, BP's fossil-based electricity generation data is far shorter than its nonfossil-based power generation data. To overcome these problems, energy-related data for 47 countries have been compiled from the IEA webpage, which covers the period between 1990 and 2017. Missing observations on electricity generation from non-fossil sources by BP are replaced with those of EIA.

Table 0.1. Description of Variables

Variable	**Label**
Dependent Variables	
lnCO2	Natural logarithm of carbon dioxide emissions, million tons,
lnEI	Natural logarithm of net energy imports, million tons of oil equivalent
Independent Variables	
lnCTP	Natural logarithm of electricity generation by coal, TWh
lnGTP	Natural logarithm of electricity generation from natural gas sources, TWh
lnSP	Natural logarithm of electricity generation by solar PV, gross output, TWh
lnWP	Natural logarithm of electricity generation from wind power, gross output, TWh
lnINDUSTRY	Natural logarithm of total final energy consumption by industry sector, ktoe
lnRESIDENT	Natural logarithm of total final energy consumption by the residential sector, ktoe
lnENERGYINTENSITY	Natural logarithm of total primary energy supply by GDP, toe per 2010 constant US$
lnGDP	Natural logarithm of current billion US$
lnPOP	Natural logarithm of total population, million
lnPOPURB	Natural logarithm of urban population, million
Dummy Variables	
EC	Dummy for global energy crisis due to high crude oil prices between 2008 and 2012
H	Countries with higher than 12375$ per capita income based on WB 2019 classification

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UM	Countries with less than 12376$ and higher than 3995$ per capita income based on WB 2019 classification
LM	Countries with less than 3996$ and higher than 1025$ per capita income based on WB 2019 classification
L	Countries with less than 1026$ per capita income based on WB 2019 classification

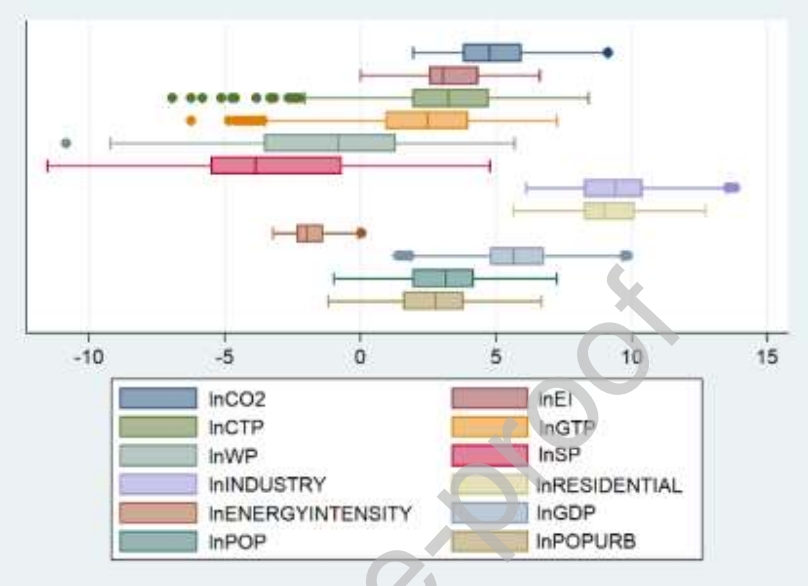


Figure 0.1. Boxplot of Variables

Table 0.2. Panel Descriptive Statistics

Variable		Mean	Std.Dev.	Min	Max	Observations		
lnCO2	overall	4.81	1.618	0.693	9.133	N	=	1292
	between		1.636	0.693	8.565	n	=	47
	within		0.207	3.866	5.809	T-bar	=	27.489
lnEI	overall	3.2	1.522	0	6.601	N	=	989
	between		1.468	0	6.127	n	=	38
	within		0.437	-1.329	5.12	T-bar	=	26.026
lnCTP	overall	3.117	2.242	-6.908	8.409	N	=	1188
	between		2.616	-5.561	7.526	n	=	45
	within		0.536	-0.721	5.459	T-bar	=	26.4
lnGTP	overall	2.248	2.33	-6.804	7.257	N	=	1232
	between		2.047	-2.309	6.606	n	=	46
	within		1.185	-2.969	5.858	T-bar	=	26.783
lnSP	overall	-3.213	3.121	-11.513	4.769	N	=	785
	between		1.864	-8.261	0.502	n	=	46
	within		2.588	-10.95	3.612	T-bar	=	17.065
lnWP	overall	-1.226	3.108	-11.744	5.687	N	=	959

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between		2.186	-6.763	2.921	n	=	44
within		2.401	-8.362	3.776	T-bar	=	21.796
between		1.395	1.334	6.648	n	=	23
within		0.484	-1.058	5.447	T-bar	=	27.696
lnINDU~Y overall	9.316	1.568	5.864	13.837	N	=	1292
between		1.58	6.502	13.127	n	=	47
within		0.246	7.946	10.362	T-bar	=	27.489
between		1.518	5.511	13.258	n	=	47
within		0.249	7.995	10.324	T-bar	=	27.489
lnRESI~L overall	9.079	1.558	5.609	12.718	N	=	1292
between		1.566	5.813	12.577	n	=	47
within		0.13	8.384	9.594	T-bar	=	27.489
lnENER~Y overall	-1.846	0.615	-3.219	0.049	N	=	1292
between		0.596	-2.991	-0.599	n	=	47
within		0.182	-2.449	-1.123	T-bar	=	27.489
lnGDP overall	5.631	1.587	1.388	9.877	N	=	1292
between		1.526	2.44	9.34	n	=	47
within		0.548	3.84	7.356	T-bar	=	27.489
lnPOP overall	2.678	1.664	-1.464	6.689	N	=	1292
between		1.674	-1.301	6.237	n	=	47
within		0.131	2.126	3.13	T-bar	=	27.489
lnPOPURB overall	2.78	1.573	-1.174	6.689	N	=	1292
between		1.584	-0.944	6.237	n	=	47
within		0.128	2.228	3.232	T-bar	=	27.489

Variables summarized in Table 0.1 and described in Figure 0.1 **Error! Reference source not found.**and Table 0.2 are included in the analyses. For most of the variables, the overall and within are calculated over 1292 years of data. The between is calculated over 47 countries. The average number of years a country is observed is 27. The table also provides mean, minimum and maximum values, and standard deviation for all variables. In general, electricity generation, GDP and GDP generating sector, industry, exhibit huge variance. Others like population, urban population, and residential do not vary much over time, but the differences among cross-sections are significant.

lnCO2 and lnEI are the dependent variables estimated. lnCO2 is estimated because it is the prime concern in climate change, as it is a by-product of power generation. lnEI is accepted as a proxy of energy security, meaning that the larger the net energy import of a nation, the greater its dependency on foreign energy sources. Being dependent on foreign energy sources brings risks to the security of a country since the current economic model is highly energy-dependent. As

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indicated before, energy bottleneck may result in social and economic turmoil. Despite air pollution and carbon emissions, coal will be used in electricity generation in the coming decades because it already exists in the energy mix, can supply continuous power, and many countries have coal reserves. lnGTP is taken due to the same reasons as lnCTP. Additionally, gas-fired power plants are seen as the best available alternatives to nuclear power, which has been seriously objected to due to inherent risks, although it is climate friendly and may provide a safeguard against the price volatility of energy. lnSP and lnWP are included because they are the key variables of this study with lnCTP since these technologies are the hope for climate change mitigation. Moreover, their role in energy security is of interest. Sectoral energy consumption data are included since sectors substantially contribute to climate change, play critical roles in energy security, and are a function of the development of nations. Energy intensity and carbon intensity are deemed important in different respects. Energy intensity is a measure of energy efficiency, the "fifth fuel", and an indicator of nations' commitment to climate change mitigation. Finally, lnGDP, lnPOPURB, and lnPOP are present in the regressions because they are the primary drivers of energy and power consumption as well as carbon emissions.

3.3. Methodology

A panel of data is formed by the combination of cross-sectional units, e.g., people, households, firms, and countries, that are observed over time. In other words, panel data is obtained by "pooling time-series of cross-sections". Generally, these cross-sectional units are referred to as individuals even they contain information on firms or countries. The number of cross-sectional units is denoted by *N*, and the number of time periods in which these units are observed is indicated by *T*. Pooling data results in a diverse source of variation, which enables more efficient parameter estimates [34],[35].

In this study, the fixed effects model is used. With the fixed effects model, taking the individuality of each unit is possible with a varying intercept and constant slope coefficients [36]. In other words, behavioral differences among cross-sections, individual heterogeneity, are assumed to be captured by the intercept. Cross-section specific, time-invariant characteristics are controlled by individual intercepts [34].

The fixed effects model is preferred in this study to consider cross-section specific unobservable factors that change over time. An example of such characteristics is the lowering of CO_2 emissions. Although governments are willing to decrease emissions, national circumstances such as population, citizens' perception and behaviors, geography, etc. are the determinants of climate change mitigation that are not easy to measure. Similarly, energy security is influenced by a nation's population, international relations, interior security, geography, or technical characteristics that change slowly or are hard to measure.

Breusch-Pagan Lagrange Multiplier Test [37] and Pesaran CD Test [38], [39] are used for the presence of cross-sectional dependence in the residuals. Cross-sectional dependence is common in panel data models and might arise because of spatial dependence, the existence of common impacts, or idiosyncratic pairwise dependence. In a world of complex and intertwined relations,

cross-sections' being correlated with each other is inevitable [40]. Misleading inference and inconsistent estimators are the likely results of cross-sectional dependence.

Hausman Test is used to check whether the error component is correlated with regressors in a random effects model. Unless there is a correlation between the error component and independent variables, estimators of both the random effects and fixed effects are consistent, and they should converge to true parameter values in large samples. If the error component is correlated with any of the regressors, only the fixed effects estimator is consistent. In such a case, for large samples, the fixed effects estimator converges to the true parameter value while the random effects estimator converges to some other value [34].

Finally, Modified Walt Test is used after estimations with fixed effects. This test is used as a statistic for groupwise heteroskedasticity in the residuals after a fixed effect model assuming homoskedasticity. A likely deviation from homoskedasticity in a panel data model is related to error variances due to characteristics of cross-sections[1].

4. Results

4.1. Specification Test ResultsCross-sectional dependence is tested first. Breusch-Pagan Lagrange Multiplier (LM) Test rejects the null hypothesis of no cross-sectional dependence at 1% significance level for all the models (see Table 0-1), which is expected since our sampling is not random and carbon emissions are the result of energy consumption, and energy is a highly traded good among the countries.

After running fixed effects and random effects models, Hausman Test is used to test the relationship of the error component with the regressors. The test results are shown below. Except for models 3, 11, and 12, the Hausman test favors the fixed effects model at 1% significance level. For models 3 and 11, significance level is 10%. Hausman Test does not differentiate for model 10.

Table 0-1 Specification Test Results

Model	Breusch-Pagan LM	Hausman	Modified Wald
1	3500.62***	38.79***	1463.97***
2	3539.30***	29.88**	2347.25***
3	2619.71***	14.36*	32014.46***
4	2632.79***	36.74***	$1.4x10^{5}$***
5	1537.08***	37.51***	15185.10***
6	1498.66***	52.38***	$6.9*10^{28}$***
7	3572.35***	96.60***	1957.73***
8	3719.94***	53.93***	2738.25***
9	1358.28***	13.30*	56999.64***
10	1365.98***		$1.4x10^{5}$***

*** p<0.01, ** p<0.05, * p<0.1

[1] Baum, C. F., 2000, Modified Wald statistics for groupwise heteroskedasticity in fixed effect model, xttest3, Statalist Distribution

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Modified Wald Test results also show cross-correlations among the cross-sections. For all the models, at 1% of significance level, there is heteroskedasticity.

4.2. Estimation Results

The Fixed Effects model is able to provide consistent but inefficient estimates due to cross-sectional dependence. To overcome this problem, Driscoll-Kraay Standard Errors [41] is used since it controls the cross-sectional dependence, and our sample has a relatively large T (=28). Estimation results are presented in Table 0-2 and Table 0-4 for Driscoll-Kraay Standard Errors. 0 presents Fixed Effects and Random Effects model results.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO2	lnCO2	lnEI	lnEI	lnEI	lnEI
lnCTP	0.2133***	0.1805***	0.3709***	0.1864***	0.2235***	0.2210***
	(0.013)	(0.012)	(0.059)	(0.029)	(0.067)	(0.049)
lnGTP	0.0466***	0.0364***	0.0851***	0.0460*	0.1175**	0.0990**
	(0.006)	(0.007)	(0.023)	(0.024)	(0.047)	(0.044)
lnSP	-0.0054***	-0.0047**			-0.0264**	-0.0555***
	(0.002)	(0.002)			(0.011)	(0.012)
lnWP	-0.0150***	-0.0119***	-0.0503***	-0.0349**		
	(0.002)	(0.003)	(0.014)	(0.016)		
lnINDUSTRY	0.4480***	0.4144***		0.7003***		
	(0.036)	(0.036)		(0.150)		
lnENERGYINTENSITY		0.2510***	-0.7738***	-0.5963***		
		(0.046)	(0.200)	(0.195)		
lnGDP	0.0432***	0.0599***	0.6053***	0.2228**	0.9116***	0.3282***
	(0.013)	(0.019)	(0.137)	(0.105)	(0.170)	(0.099)
lnPOPURB		0.5957***		0.5451**		2.7387***
		(0.066)		(0.257)		(0.556)
lnPOP	0.6395***		-2.0971***		-2.1715**	
	(0.092)		(0.727)		(0.896)	
lnRESIDENTIAL					-0.3493*	-0.4604***
					(0.177)	(0.162)
Constant	-2.5091***	-1.2638***	3.7253**	-8.1090***	7.6371***	-3.6918***
	(0.430)	(0.262)	(1.495)	(1.342)	(2.217)	(0.799)
Observations	672	672	712	712	561	561
Number of groups	40	40	35	35	36	36
r2_w	0.889	0.895	0.365	0.388	0.449	0.486
F	948.2	2174	31.56	71.54	67.89	50.43

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 0-3 and Table 0-5 also show significant estimations with the Pesaran CD test.

According to Driscoll-Kraay Standard Errors, as expected, electricity generation by solar and wind power reduces carbon emissions (95% and 99% confidence, respectively), and coal- and gas-based electricity generation contributes to carbon partial pressure in the atmosphere (99% confidence). Moreover, being an upper-mid and lower-mid income country (with increasing urban population) increases carbon emissions, while the 2008 – 2012 global energy crisis (EC)

resulted in less CO_2 emissions with increasing urban population. Energy intensity becomes important with urban population, as shown by [21].

Similar estimation results are obtained for energy security via energy dependence. As expected, electricity generation by wind and solar power reduces energy imports (99% and 95% confidence, respectively), but coal- and gas-based electricity generation contributes to foreign energy dependence (99% confidence). It is shown that having a large population improves energy security while increasing urban population brings risks. Regardless of income level, energy imports of countries increase. Having solar power in the energy mix increases the energy dependece in low-income countries. Increasing urban population and solar power improve the energy security of high-income countries.

The analyses are also conducted with urban population, lnPOPURB, instead of total population, lnPOP, to better understand the impact of urbanization on the dependent variables. Comparing the estimation results reveals that urbanization promotes climate change mitigation, although it is still a reinforcing impact with a slightly smaller coefficient than total population. However, increasing urban population is a risk for energy security as the estimation results show that lnPOPURB has a positive sign unlike lnPOP, which has a negative sign.

Table 0-2. Driscoll-Kraay Standard Error Estimations

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO2	lnCO2	lnEI	lnEI	lnEI	lnEI
lnCTP	0.2133***	0.1805***	0.3709***	0.1864***	0.2235***	0.2210***
	(0.013)	(0.012)	(0.059)	(0.029)	(0.067)	(0.049)
lnGTP	0.0466***	0.0364***	0.0851***	0.0460*	0.1175**	0.0990**
	(0.006)	(0.007)	(0.023)	(0.024)	(0.047)	(0.044)
lnSP	-0.0054***	-0.0047**			-0.0264**	-0.0555***
	(0.002)	(0.002)			(0.011)	(0.012)
lnWP	-0.0150***	-0.0119***	-0.0503***	-0.0349**		
	(0.002)	(0.003)	(0.014)	(0.016)		
lnINDUSTRY	0.4480***	0.4144***		0.7003***		
	(0.036)	(0.036)		(0.150)		
lnENERGYINTENSITY		0.2510***	-0.7738***	-0.5963***		
		(0.046)	(0.200)	(0.195)		
lnGDP	0.0432***	0.0599***	0.6053***	0.2228**	0.9116***	0.3282***
	(0.013)	(0.019)	(0.137)	(0.105)	(0.170)	(0.099)
lnPOPURB		0.5957***		0.5451**		2.7387***
		(0.066)		(0.257)		(0.556)
lnPOP	0.6395***		-2.0971***		-2.1715**	
	(0.092)		(0.727)		(0.896)	
lnRESIDENTIAL					-0.3493*	-0.4604***
					(0.177)	(0.162)
Constant	-2.5091***	-1.2638***	3.7253**	-8.1090***	7.6371***	-3.6918***
	(0.430)	(0.262)	(1.495)	(1.342)	(2.217)	(0.799)
Observations	672	672	712	712	561	561
Number of groups	40	40	35	35	36	36

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r2_w	0.889	0.895	0.365	0.388	0.449	0.486
F	948.2	2174	31.56	71.54	67.89	50.43

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 0-3. Pesaran Cross-Sectional Dependence Test Results

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO2	lnCO2	lnEI	lnEI	lnEI	lnEI
lnCTP	0.2074***	0.1805***	0.2826***	0.1864***	0.2235***	0.2210***
	(0.009)	(0.009)	(0.037)	(0.039)	(0.038)	(0.037)
lnGTP	0.0427***	0.0364***	0.0640***	0.0460**	0.1175***	0.0990***
	(0.005)	(0.005)	(0.019)	(0.019)	(0.032)	(0.031)
lnSP	-0.0028*	-0.0047***			-0.0264***	-0.0555***
	(0.002)	(0.002)			(0.008)	(0.008)
lnWP	-0.0147***	-0.0119***	-0.0240**	-0.0349***		
	(0.002)	(0.002)	(0.010)	(0.011)		
lnINDUSTRY	0.4504***	0.4144***	0.8286***	0.7003***		
	(0.019)	(0.019)	(0.103)	(0.108)		
lnENERGYINTENSITY	0.1456***	0.2510***	-0.9990***	-0.5963***		
	(0.033)	(0.035)	(0.168)	(0.176)		
lnGDP	0.0727***	0.0599***	0.3466***	0.2228***	0.9116***	0.3282***
	(0.014)	(0.014)	(0.073)	(0.075)	(0.081)	(0.087)
lnPOP	0.6562***		-2.4838***		-2.1715***	
	(0.078)		(0.387)		(0.635)	
lnPOPURB		0.5957***		0.5451*		2.7387***
		(0.064)		(0.299)		(0.389)
lnRESIDENTIAL					-0.3493**	-0.4604***
					(0.161)	(0.149)
Constant	-2.4529***	1.2638***	-1.4293	-8.1090***	7.6371***	-3.6918**
	(0.292)	(0.180)	(1.265)	(0.942)	(2.062)	(1.624)
Observations	672	672	712	712	561	561
R-squared	0.892	0.895	0.421	0.388	0.449	0.486
Number of groups	40	40	35	35	36	36
F	646.0	662.4	69.47	60.69	70.58	81.79
Rmse	0.0573	0.0567	0.351	0.360	0.334	0.323
Rho	0.996	0.993	0.991	0.951	0.992	0.993
Sigma	0.904	0.672	3.665	1.636	3.717	3.746

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 0-4. Driscoll-Kraay Standard Error Estimations with Dummy Variables

	(1)	(2)	(3)	(4)	(5)
VARIABLES	lnCO2	lnCO2	lnEI	lnEI	lnEI
lnCTP	0.2139***	0.1838***	0.3166***	0.1602***	0.2260***
	(0.013)	(0.011)	(0.053)	(0.037)	(0.048)
lnGTP	0.0468***	0.0417***	0.0896***	0.1183***	0.1075**
	(0.006)	(0.006)	(0.022)	(0.024)	(0.041)
lnSP	-0.0053***	-0.0049***		-0.0158***	-0.0522***
	(0.002)	(0.002)		(0.005)	(0.011)

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lnWP	-0.0148***	-0.0094***	-0.0223**		
	(0.002)	(0.003)	(0.009)		
lnINDUSTRY	0.4392***	0.3593***			
	(0.036)	(0.043)			
lnENERGYINTENSITY		0.2919***	-0.6985***		
		(0.053)	(0.173)		
lnGDP	0.0415***	0.1006***	0.5782***	0.6839***	0.4485***
	(0.013)	(0.029)	(0.117)	(0.098)	(0.152)
lnPOPURB		0.4681***			2.3603***
		(0.059)			(0.619)
EC		-0.0250***	-0.1131***	-0.1216***	-0.0897**
		(0.009)	(0.035)	(0.028)	(0.039)
UM	0.0344***	0.0470***	1.0218***	5.9618***	
	(0.012)	(0.010)	(0.324)	(1.764)	
LM		0.0984***	0.8900***	5.0933***	
		(0.024)	(0.259)	(1.756)	
lnPOP	0.6401***		-2.8059***	-2.0569***	
	(0.094)		(0.744)	(0.614)	
H			0.7746**	5.7244***	-0.2496***
			(0.365)	(1.746)	(0.071)
L				4.3200**	
				(1.684)	
lnRESIDENTIAL					-0.3648**
					(0.157)
Constant	-2.4195***	-0.5220*	5.8219***	0.0000	-4.0009***
	(0.420)	(0.305)	(1.776)	(0.000)	(0.884)
Observations	672	672	712	561	561
Number of groups	40	40	35	36	36
r2_w	0.890	0.902	0.438	0.555	0.498
F	1539	2822	59.40	89498	33.21

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 0-5. Pesaran Cross-Sectional Dependence Test Results with Dummy Variables

	(7)	(8)	(9)	(10)
VARIABLES	lnCO2	lnCO2	lnEI	lnEI
lnCTP	0.2055***	0.1838***	0.1603***	0.1518***
	(0.009)	(0.009)	(0.035)	(0.033)
lnGTP	0.0472***	0.0417***	0.1189***	0.0812***
	(0.005)	(0.005)	(0.030)	(0.028)
lnSP	-0.0035**	-0.0049***	-0.0166**	-0.0343***
	(0.002)	(0.002)	(0.007)	(0.007)
lnWP	-0.0115***	-0.0094***		
	(0.002)	(0.002)		
lnINDUSTRY	0.3794***	0.3593***		
	(0.020)	(0.020)		
lnENERGYINTENSITY	0.2120***	0.2919***		
	(0.033)	(0.034)		
lnGDP	0.1051***	0.1006***	0.7130***	0.3109***
	(0.016)	(0.016)	(0.095)	(0.089)
lnPOP	0.5476***		-2.0973***	

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	(0.076)		(0.639)	
EC	-0.0235***	-0.0250***	-0.1206***	-0.0774**
	(0.006)	(0.006)	(0.033)	(0.032)
UM	0.0772***	0.0470***	0.2048**	
	(0.014)	(0.015)	(0.102)	
LM	0.1113***	0.0984***	-0.6455***	-1.0097***
	(0.017)	(0.017)	(0.192)	(0.133)
lnPOPURB		0.4681***		1.3367***
		(0.066)		(0.401)
L			-1.4320***	-1.6664***
			(0.235)	(0.189)
Y2000			0.2064**	0.1742**
			(0.084)	(0.084)
Constant	-1.4563***	-0.5220**	6.4455***	-3.1052***
	(0.307)	(0.212)	(1.967)	(1.017)
Observations	672	672	561	561
R-squared	0.902	0.902	0.560	0.556
Number of groups	40	40	36	36
F	522.4	520.4	59.49	71.67
Rmse	0.0546	0.0547	0.300	0.301
Rho	0.994	0.989	0.993	0.975
Sigma	0.724	0.511	3.648	1.911

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

5. Discussion and Conclusion

Climate change is basically driven by the energy sector, and the share of electricity generation is as important as the share of the transportation sector. Therefore, long-term planning of energy policies is vital for mitigating climate change since climate change and energy security issues are interrelated. The central assumption is that climate change threatens energy security, but since the link between them is complex, positives and negatives should be carefully assessed before policy-making [14]. Energy security is the sole aim of the energy policy of a country. When the concept first emerged, it was only referring to oil security because dependence on foreign oil has direct and indirect impacts on the economy as a whole through price fluctuations due to supply interruption [42]. Through decades, energy security has evolved, and today it has a far broader scope concerned with sustainability, affordability, and continuity.

This study aims to analyze the impact of different variables on securing energy and reducing carbon emissions, and attains this aim by panel econometrics with fixed effects model since fixed effects enable unobserved variables' impacts to be effective on explanatory variables. However, due to the presence of cross-sectional dependence, Driscoll-Kraay Standard Errors is used since it controls cross-sectional dependence and the sample has a relatively large T. The results indicate that electricity generation by solar and wind helps both securing energy and climate change mitigation as anticipated. However, the dataset reveals that coal- and gas-based power generation does not contribute to global energy security. This is because hard coal is generally used in electricity generation, and it is a widely imported fuel as there are a few countries, e.g., South Africa, Australia, and Russia, with ample hard coal reserves, as underlined

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by [43]. The same is valid for gas. There are more countries with gas reserves than countries with coal reserves, but the unequal distribution of gas makes it an export good.

The dataset does not cast any distinct role on energy efficiency in terms of energy intensity. Increasing energy intensity, i.e., decreasing energy efficiency releases more carbon as anticipated. However, increasing energy intensity, i.e., decreasing energy efficiency, contributes to the energy security of the countries with wind power in the energy mix.

One interesting result is that having a large population promotes energy security, but increasing urban population brings risks. The latter is attributed to the higher energy consumption by urban population, as shown by [44]–[46]. On the other hand, having a large population requires investment in energy infrastructure since the focus for such nations is on using domestic sources, considering energy prices and additional costs. Countries with a small total population may choose to import power because this may be cheaper, or they can meet the demand even with a single power station. In other words, increasing urban population bear risks for a country's energy security since urban areas are the hubs that require high energy and material input. On the other hand, having a large population necessitates investment in energy security as it is impossible to meet energy demand via a single power plant or energy imports, as in the case of countries with small populations.

The results also indicate that energy imports are rising regardless of income level, and upper-mid income is the highest. However, having a large urban population and solar power in the energy mix means less energy imports for the high-income countries, which is also related to residential energy consumption. In other words, solar's use in large urban areas for residential needs improves the energy security of high-income countries. Moreover, upper- and lower-mid income countries continue emitting significantly more CO_2, which emphasizes the need to support these countries in their climate change mitigation efforts.

To conclude, focusing on alternatives is helpful in both climate change mitigation and securing energy. Nevertheless, almost all nations have one kind of fossil reserve; their exploitation will be vital for the coming decades until a technological breakthrough occurs so that intermittent characteristics of wind and solar will not be a threat anymore to continuous and affordable energy supply. Besides, policymakers need to concentrate on demand management as the estimations reveal the role of urban population both in climate change and energy security. The impacts of climate change are already so compelling that progress in technology alone is not promising for the future of human being.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. FE and RE Model Results

Table A- 1. Fixed Effects Model Estimations

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO2	lnCO2	lnEI	lnEI	lnEI	lnEI
lnCTP	0.2074***	0.1805***	0.2826***	0.1864***	0.2235***	0.2210***
	(0.009)	(0.009)	(0.037)	(0.039)	(0.038)	(0.037)
lnGTP	0.0427***	0.0364***	0.0640***	0.0460**	0.1175***	0.0990***
	(0.005)	(0.005)	(0.019)	(0.019)	(0.032)	(0.031)
lnSP	-0.0028*	-0.0047***			-0.0264***	-0.0555***
	(0.002)	(0.002)			(0.008)	(0.008)
lnWP	-0.0147***	-0.0119***	-0.0240**	-0.0349***		
	(0.002)	(0.002)	(0.010)	(0.011)		
lnINDUSTRY	0.4504***	0.4144***	0.8286***	0.7003***		
	(0.019)	(0.019)	(0.103)	(0.108)		
lnENERGYINTENSITY	0.1456***	0.2510***	-0.9990***	-0.5963***		
	(0.033)	(0.035)	(0.168)	(0.176)		
lnGDP	0.0727***	0.0599***	0.3466***	0.2228***	0.9116***	0.3282***
	(0.014)	(0.014)	(0.073)	(0.075)	(0.081)	(0.087)
lnPOP	0.6562***		-2.4838***		-2.1715***	
	(0.078)		(0.387)		(0.635)	
lnPOPURB		0.5957***		0.5451*		2.7387***
		(0.064)		(0.299)		(0.389)
lnRESIDENTIAL					-0.3493**	-0.4604***
					(0.161)	(0.149)
Constant	-2.4529***	-1.2638***	-1.4293	-8.1090***	7.6371***	-3.6918**
	(0.292)	(0.180)	(1.265)	(0.942)	(2.062)	(1.624)
Observations	672	672	712	712	561	561
R-squared	0.892	0.895	0.421	0.388	0.449	0.486
Number of groups	40	40	35	35	36	36
F	646.0	662.4	69.47	60.69	70.58	81.79
Rmse	0.0573	0.0567	0.351	0.360	0.334	0.323
Rho	0.996	0.993	0.991	0.951	0.992	0.993
Sigma	0.904	0.672	3.665	1.636	3.717	3.746

Table A- 2. Random Effect Model Estimations

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO2	lnCO2	lnEI	lnEI	lnEI	lnEI
lnCTP	0.1974***	0.1895***	0.1937***	0.1927***	0.1926***	0.2217***
	(0.009)	(0.009)	(0.033)	(0.033)	(0.033)	(0.032)
lnGTP	0.0451***	0.0424***	0.0601***	0.0617***	0.1173***	0.0788***
	(0.005)	(0.005)	(0.019)	(0.019)	(0.030)	(0.020)
lnSP	-0.0034**	-0.0044***			-0.0368***	
	(0.002)	(0.002)			(0.007)	

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lnWP	-0.0112***	-0.0106***	-0.0285***	-0.0286***		-0.0469***
	(0.002)	(0.002)	(0.010)	(0.010)		(0.009)
lnINDUSTRY	0.4386***	0.4201***	0.7190***	0.6315***		
	(0.018)	(0.019)	(0.096)	(0.099)		
lnENERGYINTENSITY	0.1154***	0.1500***	-0.5346***	-0.6168***		
	(0.032)	(0.030)	(0.147)	(0.145)		
lnGDP	0.1090***	0.0971***	0.3088***	0.2873***	0.7598***	0.5946***
	(0.014)	(0.014)	(0.072)	(0.073)	(0.065)	(0.057)
lnPOP	0.1728***		-0.4061***		0.0218	
	(0.026)		(0.093)		(0.130)	
lnPOPURB		0.2280***		-0.2354**		0.1780
		(0.029)		(0.103)		(0.114)
lnRESIDENTIAL					-0.2976**	-0.2203*
					(0.133)	(0.116)
Constant	-0.9034***	-0.6546***	-5.8302***	-5.6633***	0.3948	0.3742
	(0.149)	(0.144)	(0.679)	(0.712)	(0.932)	(0.856)
Observations	672	672	712	712	561	712
Number of groups	40	40	35	35	36	35
Rmse	0.0598	0.0590	0.362	0.366	0.340	0.379
Rho	0.937	0.938	0.750	0.737	0.847	0.696
Sigma	0.228	0.228	0.701	0.703	0.852	0.675
r2_w	0.885	0.889	0.394	0.380	0.433	0.334

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix B. List of Countries

Table C- 1 List of Countries

Name	Code	EU	OECD	ASEAN	BRICS	n
Australia	AUS	0	1	0	0	28
Austria	AUT	1	1	0	0	28
Belgium	BEL	1	1	0	0	28
Brazil	BRA	0	0	0	1	28
Canada	CAN	0	1	0	0	28
Switzerland	CHE	0	1	0	0	26
Chile	CHL	0	1	0	0	28
China	CHN	0	0	0	1	28
Colombia	COL	0	1	0	0	28
Czech Republic	CZE	1	1	0	0	28
Germany	DEU	1	1	0	0	28
Denmark	DNK	1	1	0	0	28
Spain	ESP	1	1	0	0	28

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Estonia	EST	1	1	0	0	25
Finland	FIN	1	1	0	0	28
France	FRA	1	1	0	0	28
United Kingdom	GBR	0	1	0	0	28
Greece	GRC	1	1	0	0	28
Hungary	HUN	1	1	0	0	27
Indonesia	IDN	0	0	1	0	28
India	IND	0	0	0	1	28
Ireland	IRL	1	1	0	0	28
Iceland	ISL	0	1	0	0	28
Israel	ISR	0	1	0	0	28
Italy	ITA	1	1	0	0	28
Japan	JPN	0	1	0	0	28
Korea, Rep.	KOR	0	1	0	0	28
Luxembourg	LUX	1	1	0	0	28
Latvia	LVA	1	1	0	0	22
Mexico	MEX	0	1	0	0	28
Myanmar	MMR	0	0	1	0	18
Malaysia	MYS	0	0	1	0	28
Netherlands	NLD	1	1	0	0	28
Norway	NOR	0	1	0	0	28
New Zealand	NZL	0	1	0	0	28
Philippines	PHL	0	0	1	0	28
Poland	POL	1	1	0	0	28
Portugal	PRT	1	1	0	0	28
Russian Federation	RUS	0	0	0	1	28
Singapore	SGP	0	0	1	0	26
Slovak Republic	SVK	1	1	0	0	28
Slovenia	SVN	1	1	0	0	28
Sweden	SWE	1	1	0	0	28
Thailand	THA	0	0	1	0	28
Türkiye	TUR	0	1	0	0	28
United States	USA	0	1	0	0	28
South Africa	ZAF	0	0	0	1	28

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