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Original Article

The relationship between energy consumption and per capita income in Bangladesh♣

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Abstract

Higher energy consumption is one of the crucial factors that contributes to economic growth of developing countries like Bangladesh. Considering per capita income as dependent variable and six other independent variables, the Augmented Dickey Fuller (ADF) test results show that all variables are stationary either at their first differences, I (1), or at level data, I (0). Auto Regressive Distributed Lag (ARDL) model for mixed combination shows that there is a long run relationship between energy consumption and per capita income. The Wald test shows that per capita income is influenced by natural gas consumption and petroleum consumption. Results from the Granger causality test reveal that number of electricity customers and natural gas consumption granger causes per capita income in the long run. For rapid development, the country should develop a sustainable energy policy and invest more in energy sector that will focus on using more renewable energy.

Keywords: per capita income, energy consumption, time series data analysis, auto regressive distributed lag (ARDL) model, causality

1. Introduction

Energy is essential for economic and social development and for building a better quality of life, especially in developing countries like Bangladesh (Murshed, Abbass, & Rashid, 2020). Sustainable energy supports industrial growth, modern agriculture, increased trade and improved transportation. Bangladesh faces a severe energy crisis in serving its huge population of about 165 million, because it has only limited reserves of natural gas, coal and biomass. The natural gas reserve is expected to completely run out by 2041 (Islam, Al-Amin, & Sarkar, 2021). The country is heavily dependent on imported petroleum, which is mostly used for transportation and electricity production. Bangladesh has earned a production capacity of about 25,774 MW of electricity, whereas the demand is about 15,000 MW (Munjer, Hasan, Hossain, & Rahman, 2023). Unfortunately, Bangladesh is one of those countries that use the least amount of renewable energy sources. Economic growth of Bangladesh has accelerated over the last few years. Both the GDP and the per capita income have almost doubled in the last 7 years. Many factors have contributed to this massive socio-economic development, such as remittances, exports of ready-made garments, higher energy consumption, huge investments in infra-structure and mega projects, etc. Energy demand is being met through imported fossil fuel, LPG and LNG. Biomass is also used at a massive scale in the rural areas, mainly for household needs. The country has started using renewable

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energy sources although this is very insignificant, only 3% of the total energy. Estimated total energy consumption in the country is about 57.20 MTOE. On average energy consumption is increasing at a rate of 6% per year. Per capita consumption of energy in Bangladesh is on an average 346 kgOe (Kilogram Oil Equivalent) and per capita generation of electricity is 608.76 kWh with access to electricity covering 100% of the total population. Energy consumption from different sources is listed in Table 1.

Several studies were conducted to explore the relationship between energy consumption and economic performance. Most of the studies have chosen GDP as the economic performance indicator and have taken only electricity consumption as independent variable. We have considered seven energy related independent variables to get a wider perspective of the relationship for better policy implications. Per capita income is one of the strongest economic indicators, as is gross domestic product (GDP). GDP may be affected by population growth, but per capita income is free from this limitation. We have explored the existence and direction of causal relationship between energy consumption and per capita income. An Auto regressive distributed lag (ARDL) model-based Granger causality test was used to analyze this relationship. A short term and long-term positive relationship between these variables may help us conclude that higher energy consumption will lead to economic growth of the country.

The objective of this study was to quantify the relationship between energy consumption and per capita income in a developing country, represented by Bangladesh. Using different types of calculations, we have shown a strong relationship between them. Considering per capita income as the dependent variable and six other independent variables, the Augmented Dickey Fuller (ADF) test, Auto Regressive Distributed Lag (ARDL) model, Wald test, and Granger causality test prove the relationship between energy consumption and per capita income. A strong correlation has been observed between the cost of power plants and corruption, the statistical analysis suggesting that higher levels of corruption lead to higher capital costs. A sustainable energy and power expansion policy depends on research, education, training, and knowledge management activities. Our study shows that there is a strong correlation between economic growth and energy consumption.

Table 1. Energy consumption by Bangladesh in the year 2021-2022, in MTOE

Source	Unit	Amount	Mtoe
Oil (Crude + Refined)	K ton	10509.167	10.51
LPG	K ton	1543	1.54
Natural Gas	Bcf	842.01	19.52
LNG	Bcf	240.56	5.58
Coal (Imported)	K ton	6140	3.88
Coal (Local)	K ton	488.724	0.31
RE (Hydro)	MW	230	0.17
RE (Solar+ wind)	MW	717.5	0.53
Electricity (Imported)	MW	1160	0.86
Total Commercial			42.90
Biomass			14.30
Total primary			57.20

Source: HCU Data Bank

2. Relationship between Energy Consumption and Economic Growth

Per capita electricity generation in years 2021-22 was 518 kWh, whereas consumption was 464 kWh (Bangladesh Power Development Board, 2022). In Bangladesh, more than 40% of power is consumed by the domestic sector, which is comparatively higher than in most other countries. Although agriculture is a vital part of Bangladesh economy, it consumes only 3% energy. The available renewable energy types of Bangladesh are solar, biomass, wind, hydropower and geothermal energy (Sarker *et al.* 2022; Uddin-Rahman *et al*., 2019). Figure 1 shows the percentages of renewable energy sources in the country. Only two sources, namely solar and hydro, provide about 99 percent of the total renewable energy.

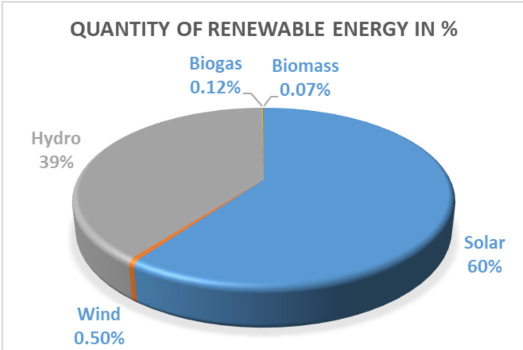

Figure 1. Renewable energy sources and amounts in Bangladesh (SREDA, 2019)

Bangladesh economy has been growing steadily over a decade crossing 7.0 percent in FY 2015-16 and 8.0 percent in FY 2018-19. The economy grew by 6.94 percent in FY 2020-21 and 7.10 percent in FY 2021-22. The volume of GDP at current market prices reached BDT 39,717,164 million in FY 2021-22. Figure 2 depicts yearly per capita income of Bangladesh from 1971-72 to 2021-22. Per capita gross national income increased to US$ 2,793 in FY 2021-22, US$ 202 up from FY 2020-21 (Bangladesh Economic Review, 2023). Bangladesh has gained remarkable growth in income in the recent years. Average growth rate of per capita income for 2011–2021was 5.29% (Vasagan, 2022).

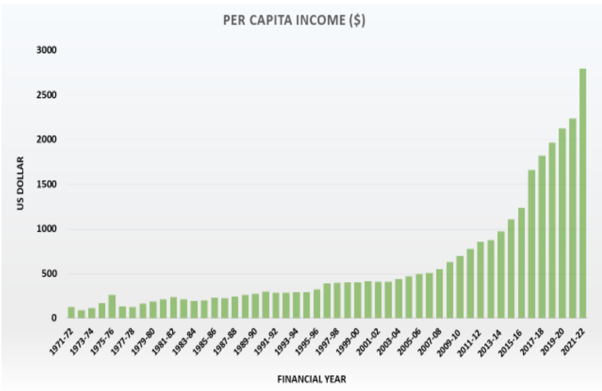

Figure 2. Per capita income in Bangladesh (1971-2022)

GDP growth rate is an important indicator and has proven relationships with electricity consumption, agriculture, transparency, education, capital formation, foreign direct investment, natural resources, carbon dioxide emissions, natural gas consumption, population, exports, garment industry, micro-credit, growth of urban GDP, export rice harvests, labor force, domestic savings, and tourism (Salma, Hasan, & Sultana, 2020). Rahman, Rana, & Barua (2019) have shown that energy use, gross capital formation and remittances are the main drivers of economic growth in South Asian countries.

Zhang, Nuruzzaman, & Su (2021) investigated the household electricity and gas consumption and its effect on Bangladesh's economic growth. Autoregressive Distributed Lag (ARDL) bound test was used in this study. The country's labor-intensive economy has been found to have a unidirectional relationship from residential electricity consumption and population growth. Dey (2019) has mentioned that existence of a strong relationship between electricity consumption and gross domestic product (GDP) does not necessarily mean that they have a causal relationship as well. Instead, she established a relationship between energy consumption and per capita income. Using the Vector error correction model (VECM), the results of both long-run and joint causality exhibit strong bidirectional causal relationship between per capita energy consumption and per capita real income.

3. Methodology

3.1 Data and variables

Per capita income has been used as dependent variable, whereas other data are used as independent variables. 32 years of data from 1990 to 2021 have been collected from various sources. The variables and their definitions are shown in Table 2 with sources.

Table 2. List of variables, their definitions, and sources of data

Variable	Definition	Unit	Source of data
INC	Per Capita Income	USD	World Bank
PGEN	Net Power Generation in	GWh	Bangladesh Power Development Board (BPDB)
PCON	Per Capita Power Consumption	KWh	BPDB
SLOSS	Distribution System Loss	%	BPDB
NCUS	Number of Electricity Customers		BPDB
PETC	Petroleum consumption	Thousand barrels/day	Bangladesh Petroleum Corporation (BPC)
NGAS	Natural Gas consumption	Billion cubic feet	Bangladesh Oil, Gas, and Mineral Corporation (Petrobangla)
TEC	Total Energy Consumption	Kiloton Oil Equivalent (ktoe)	World Energy Information

3.2 Data Analysis methods

Various time series data analysis methods have been applied using E-views (10) software. The following macro-econometric models have been used mainly to analyze the time series data.

- Correlation
- Multiple Regression Analysis
- ADF (Augmented Dicky Fuller)
- PP (Philips and Perron)
- ARDL (Auto Regression Distributed Lag)
- Granger Causality

3.3 Correlation

The correlation coefficient measures the strength of relationship between two sets of interval-scaled or ratio-scaled variables (Lind, 2017). It ranges from -1 up to and including 1.

Coefficient of correlation: $$r = \frac{\Sigma(X - \bar{x})(Y - \bar{y})}{(n-1)sXsY} \quad (1)$$

In this equation, X = independent variable, Y= dependent variable, $\bar{x}$ = mean value of x variables, $\bar{Y}$ = mean value of y variables, n = number of observations, and sX and sY are standard deviations of x and y.

3.4 Multiple regression analysis

Multiple regression is a statistical method that is used to analyze the relationship between a single dependent variable and several independent variables (Ghani and Ahmad, 2010).

The regression equation is: $$Y_t = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \ldots\ldots + \beta_nX_n + \varepsilon_t \quad (2)$$

Here, Y_t = dependent variable (per capita income), X_1 to X_n = independent variables, α is the intercept (or constant), t represents the year, β_1 to β_n are coefficients for X variables, and ε_t = an error term.

3.5 Stationarity test

A reliable stationarity test that yields unbiased test results is important as it is the prerequisite for a suitable forecasting model development (Bawdekar & Pustry, 2022). The statistical properties of a stationary time series including mean, variance, and autocovariance that are all constant over time. Stationarity is crucial because all typical results of classical regression analysis are acceptable when the time series is found to be stationary. Regression results with non-stationary time series may be meaningless (Gujarati & Porter, 2009). Stationarity is checked with various unit root tests.

Unit root tests without structural breaks:

- ADF unit root test

ADF unit root test is applied to examine the presence of unit root of each variable where the null of non-stationarity has been tested against the alternative of stationarity (Dickey and Fuller, 1979). The ADF unit root test is based on the following equation:

$$\Delta Y_t = \mu + \beta t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + \varepsilon_t \quad (3)$$

where, μ = a constant, ΔY_t = first difference of Y_t or $Y_t - Y_{t-1}$, μ = a constant term, α = coefficient of Y_{t-1}, t = a time trend variable, and ε_t = white noise error term.

- PP Unit Root Test

PP unit root test is applied because its states statistics are strong for serial correlation and heteroscedasticity (Ahmed *et al*., 2023). The null of non-stationarity is tested against the alternative of stationarity (Phillips and Perron, 1988). The following equation is used for PP test:

$$\Delta Y_t = \mu + \beta t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + \varepsilon_t \quad (4)$$

where ε_t (white noise error term) is *I*(0) and heteroskedastic, Y_{t-1} is a deterministic trend component, and α is a constant.

3.6 ARDL model

An autoregressive distributed lag (ARDL) model is an ordinary least squares (OLS) based approach which is applicable for both non-stationary time series as well as for times series with mixed order of integration (Pesaran & Yongcheol, 2013). A dynamic error correction model (ECM) can be derived from ARDL. Likewise, the ECM integrates the short-run dynamics with the long-run equilibrium and avoids problems such as spurious relationship resulting from non-stationary time series data (Shrestha & Bhatta, 2017). To illustrate the ARDL model, the following simple equation can be considered.

$$y_t = \alpha + \beta x_t + \delta z_t + e_t \quad (5)$$

where α is a constant term, β and δ are coefficient of x and z variables, and e_t is the error term.

The error correction version of the ARDL model is as follows:

$$\Delta y_t = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \sum_{i=1}^{p} \delta_i \Delta x_{t-i} + \sum_{i=1}^{p} \varepsilon_i \Delta z_{t-i} + \lambda_1 y_{t-1} + \lambda_2 x_{t-1} + \lambda_3 z_{t-1} + u_t \quad (6)$$

The first part of the equation with β, δ and ε represents short run dynamics of the model. The second part with λs represents long run relationship. The null hypothesis in the equation is $\lambda_1 + \lambda_2 + \lambda_3 = 0$, which means non-existence of long run relationship.

3.7 Causality test

If two variables Y and X are cointegrated, then there may exist any of the 3 relationships: a) X affects Y, b) Y affects X, and c) X and Y affect each other. To determine the pattern of such relationship, Granger (1969) has developed a causality test method. If current and lagged values of X improve the prediction of the future value of Y, then it is said that X 'Granger causes' Y. The simple model of Granger causality is as follows:

$$\Delta Y_t = \sum_{i=1}^{n} \alpha_i \Delta Y_{t-i} + \sum_{j=1}^{n} \beta_j \Delta X_{t-j} + u_{1t} \quad (7)$$

where, the $\boldsymbol{\alpha_j}$ and $\boldsymbol{\beta_j}$ are the regression coefficients and $\boldsymbol{u_{1i}}$ is the error term. Equation (7) shows that the current value of ΔY is related to the past values of itself and the past values of ΔX. The null hypothesis in Equation (7) is $\boldsymbol{\beta_j} = 0$ which means, "ΔX does not Granger cause ΔY".

$$\Delta X_t = \sum_{i=1}^{n} \lambda_i \Delta X_{t-i} + \sum_{j=1}^{n} \delta_j \Delta Y_{t-j} + u_{2t} \quad (8)$$

where the λ_j and δ_j are the regression coefficients and $\boldsymbol{u_{2i}}$ is the error term. Equation (8) postulates that ΔX is related to the past values of itself and those of ΔY.

4. Results and Discussion

4.1 Correlation between energy consumption and per capita income

Our calculations show a strong positive correlation between per capita income and each of the other variables. This means when any of these variables increases, per capita income also increases. Only distribution system loss shows a strong negative correlation, that means when system loss decreases, per capita income increases. Dey (2019) also found strong correlation coefficient of 0.996 between per capita energy consumption and per capita income, which is 0.986 in our analysis; and her correlation between number of customers and income was 0.972 and our correlation is 0.905. The correlations between the different variables are shown in Table 3.

Table 3. Correlations between the variables

	INC
INC	1
PGEN	0.989375
PCON	0.986638
SLOSS	-0.801729
NCUS	0.904789
PETC	0.969562
NGAS	0.890898
TEC	0.950243

4.2 Multiple regression analysis (Per capita income)

Per capita income is the function of seven regressors and the regression equation is:

$$INC = \alpha + \beta_1 PGEN + \beta_2 PCON + \beta_3 SLOSS + \beta_4 NCUS + \beta_5 PETC + \beta_6 NGAS + \beta 6TEC + \varepsilon_t \quad (9)$$

On the basis of the analysis results, the regression equation for per capita income can be written as:

$$INC = -276.1418 + 0.010789\ PGEN + 5.758688\ PCON + 12.09723\ SLOSS -2.75E\text{-}05\ NCUS + 1.262200\ PETC + 0.126978\ NGAS + -0.019584\ TEC + 101833.4 \quad (10)$$

4.3 Stationarity test

Our calculation for stationary test shows that mixed order of integration is found from the unit root tests. Most of the variables are stationary at 1st order of integration according to both ADF and PP methods. Only distribution system loss variable shows stationarity at level data in both methods. Considering this overall, we can state that the variables are a combination of stationarity at I(0) and I(1). When there is a mixed order of integration with I(1) and I(0), the ARDL method can be used for developing a relationship among the variables (Shrestha & Bhatta, 2018). Summary of the test results is shown in Table 4.

4.4 ARDL model test

The basic ARDL model shows that the p-values of all the variables, except for natural gas consumption, are greater than 5%. This means that only the natural gas consumption has an impact on per capita income. The other variables' impacts are not significant. ARDL results are shown in Table 5.

If F value is higher than I (1) value at 5% level of significance, we reject the null hypothesis and conclude that a long run relationship and cointegration exists. Here, F statistic is 3.55438, which is greater than I (1) = 3.21 (at 5% significance level). So, there is a long run relationship between energy consumption and per capita income. In the Restricted Constant and No Trend Results, the p values of all the variables are more than 0.05, so the coefficients individually have no long-term effects on per capita income. A similar study exhibits the presence of cointegrating relationships among the dependent variables, namely, renewable energy consumption, real GDP, and natural gas consumption from ARDL bound test (Kayesh & Siddiqa, 2023). EC is the error correction term, and it is the residual form long term equation. Then we shall estimate the Error Correction Model (ECM).

The coefficient of ARDL Error Correction Regression results t_{-1} shows speed of adjustment from short run to long run equilibrium and it should have a negative sign and be statistically significant. Table 6 shows the long test run and bounds test results.

Table 5. List of ARDL test results

Variable	Coefficient	t-Statistic	Prob.*
INC	0.841848	3.146613	0.0059
PGEN	-0.004546	-0.229994	0.8208
PCON	3.310170	0.880642	0.3908
SLOSS	6.755689	0.740128	0.4693
NCUS	2.38E-05	0.405632	0.6901
NGAS	0.258810	0.507113	0.6186
NGAS(-1)	1.700182	2.396924	0.0283
NGAS(-2)	-1.764956	-2.205084	0.0415
PETC	1.078718	1.087364	0.2921
TEC	-0.009830	-0.455004	0.6549
TEC (-1)	0.024945	0.951196	0.3548
TEC (-2)	-0.034422	-1.898171	0.0748
C	-200.6534	-0.375719	0.7118
Sum squared resid	35218.37	11.37986	
F-statistic	502.1394	2.627383	
Prob (F-statistic)	0.000000		

Table 4. Summary of unit root tests

ADF Test				
Level		1st Difference		Order of Integration
t-Statistic	p-value	t-Statistic	p-value	
1.140786	0.9999	-4.403503	0.0078	I (1)
2.415114	1.0000	-7.439522	0.0000	I (1)
-2.776679	0.2158	-6.128223	0.0001	I (1)
-1.240051	0.8819	-2.023382	0.5629	I (2)
-4.009775	0.0225	-6.244449	0.0001	I (0)
-1.676982	0.7373	-4.917207	0.0023	I (1)
-0.055817	0.9932	-5.600491	0.0005	I (1)
-0.297394	0.9870	-4.638773	0.0053	I (1)
PP Test				
t-Statistic	p-value	t-Statistic	p-value	
1.140786	0.9999	-4.416146	0.0076	I (1)
3.261063	1.0000	-7.194272	0.0000	I (1)
-2.733197	0.2311	-7.036584	0.0000	I (1)
3.322493	1.0000	-6.595935	0.0000	I (1)
-3.674278	0.0395	-6.777167	0.0000	I (0)
-1.875049	0.6431	-5.104855	0.0014	I (1)
-0.016228	0.9941	-4.652051	0.0043	I (1)
0.250636	0.9974	-20.03605	0.0000	I (1)

Table 6. ARDL long run form and bounds test

EC = INC - (-0.0287*PGEN + 20.9303*PCON + 42.7164*SLOSS + 0.0002*NCUS + 1.2269*NGAS + 6.8208*PETC-0.1221*TEC-1268.7380)

F-Bounds Test		Null Hypothesis: No levels relationship	
Value	Significance	I(0)	I(1)
3.553818	10%	1.92	2.89
7	5%	2.17	3.21
	2.5%	2.43	3.51
	1%	2.73	3.9

Source: Researchers' computation

The Wald test is typically used to explore whether an independent variable has a significant relationship with a dependent variable. Summary of the results of Wald test is listed in Table 7. Here, the test shows that Net power generation, per capita power consumption, distribution system loss, and number of electricity customers, natural gas consumption, and total energy consumption do not affect the per capita income in the short run. But petroleum consumption has short run effect on per capita income. In another research (Guefano-Bozorg *et al*., 2023) similar to this study, the Wald test results indicate that there is no short-term causality from electricity consumption to per capita GDP and other variables.

Table 7. Summary of the results of Wald test

Independent variable	P-value of F test	P-value of Chi-square	Test result
PGEN	0.8208	0.8181	Insignificant
PCON	0.3908	0.3785	Insignificant
SLOSS	0.4693	0.4592	Insignificant
NCUS	0.6901	0.6850	Insignificant
PETC	0.0729	0.0396	Significant
NGAS	0.2921	0.2769	Insignificant
TEC	0.2039	0.1740	Insignificant

Source: Researchers' computation

4.5 Granger causality test

Our GCT test shows that out of the seven independent variables, two variables have p-values less than 0.05. That means these two variables, namely number of electricity customers and natural gas consumption granger cause per capita income. On the other hand, per capita income granger causes number of customers, petroleum consumption and natural gas consumption. Table 8 shows the Granger Causality Test results. Although our results show no Granger causality between power consumption and income, Amin and Murshed (2017) observed a long run unidirectional granger causality between power consumption and economic growth.

Table 8. Granger causality test results

Null Hypothesis	F-Statistic	Probability
PGEN does not Granger Cause INC	2.93117	0.0718
INC does not Granger Cause PGEN	1.60912	0.2201
PCON does not Granger Cause INC	2.94103	0.0713
INC does not Granger Cause PCON	2.88125	0.0748
SLOSS does not Granger Cause INC	1.20637	0.3161
INC does not Granger Cause SLOSS	0.21711	0.8063
NCUS does not Granger Cause INC	5.41876	0.0111
INC does not Granger Cause NCUS	14.2530	7.E-05
NGAS does not Granger Cause INC	8.11611	0.0019
INC does not Granger Cause NGAS	12.1964	0.0002
PETC does not Granger Cause INC	1.76443	0.1920
INC does not Granger Cause PETC	5.59479	0.0098
TEC does not Granger Cause INC	2.30825	0.1202
INC does not Granger Cause TEC	0.81971	0.4521

5. Conclusions

The study results clearly indicate that energy consumption can be considered as a primary condition for attaining higher economic growth in Bangladesh. Therefore, energy policy regarding electricity generation, distribution, management, and conservation should be given priority to secure higher economic growth. Using different types of calculations, we have shown a strong relationship between per capita income and energy consumption. Considering per capita income as the dependent variable and six other independent variables, the Augmented Dickey Fuller (ADF) test, Auto Regressive Distributed Lag (ARDL) model, Wald test, and Granger causality test prove the relationship between energy consumption and per capita income. Power sector is too much dependent on natural gas. Natural gas exploration should be enhanced immediately. Reliance on imported oil may be reduced by using more renewable energy sources and energy diversification. A strong correlation between the cost of power plants and corruption was found by statistical analysis, suggesting that higher levels of corruption lead to higher capital costs. A sustainable energy and power expansion policy depends on research, education, training, and knowledge management activities. There are few in-country experts in energy system planning, exploration and production, energy economics, energy management, and energy diplomacy. Adequate investment and human resources development policies are essential to ensure the stable supply of sufficient energy. Sustainable energy policy may be achieved by diversification of energy mix, by using more coal-based power plants, massive use of renewable energy, and by exploring oil and gas both in inland and in the sea. Our study shows that there is a strong correlation between economic growth and energy consumption.

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