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Analysis of the Relationships among Financial Development, Economic Growth, Energy Use, and Carbon Emissions by Co-Integration with Multiple Structural Breaks

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Abstract: In this study, the effects of financial and economic development on energy consumption and CO_2 emissions are analyzed using multiple structural breaks, second-generation panel unit root tests, the Westerlund Cointegration Test, and PMG and MG estimators. Unlike classical studies, financial development is included, in the analysis, as an indicator of the accumulated capital as a result of industrial production that has been realized for many years. We conducted a panel data analysis on 13 developing countries for which we could obtain uninterrupted data in the Morgan Stanley Developing Countries index. We found significant relationships between economic growth, energy usage, and CO_2 emissions. Financial development and carbon emissions are cointegrated in the long-term, and financial development is found to accelerate environmental pollution. Therefore, energy economists should consider the effect of financial development on energy use and carbon emissions in future studies. Policy-makers in emerging markets are also advised to take necessary actions to reduce carbon emissions while increasing financial development. It is important that the same results were obtained in medium- and small-scale countries, as well as in large economies (e.g., China) under the scope of this review.

Keywords: multiple structural breaks; carbon emission; financial development; sustainable environment

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1. Introduction

Since the study of John Kraft and Arthur Kraft [1], studies focused on the relationships among energy consumption, carbon emissions, and economic growth have attained remarkable numbers. A significant part of the economic development of developed countries is based on production. However, an increase in production brings with it the problem of increasing energy consumption and carbon emissions. Especially after the 1980s, the release of greenhouse gases has begun to have a significant impact on human life and the livable environment, triggering global warming and starting irreversible damage.

The United Nations, the largest organization in the world, brought the issue to the attention of the Rio conference in 1992 with the "bilateral amendment environmental contract" and, in 1997, the Kyoto protocol was opened for signing. After the Kyoto Protocol came into force in 2005, until the year 2012, developed countries committed to decrease their carbon emissions to the level before the year of 1990. The fact that developing countries have not been included in the Kyoto protocol, which has been signed by 55 developed countries in total, has become an important problem over the short time since then.

In developing countries, production-associated CO_2 emissions have increased continuously. For example, from 1990 to 2014, the total carbon emissions in the U.S. increased by 142%, compared to 439% in India and 1206% in China [2].

Developed countries have a significant global share in terms of the total energy demand and CO_2 emissions. However, the efforts of developed countries in promoting clean energy have begun to yield results, although they are more costly. The fact that developing countries prefer fossil fuels, which are cheaper, makes the problem of their CO_2 emissions much more important than ever. Similarly, uncertainties should be taken into account in the design of energy markets. A sustainable energy supply is at least as important as a clean energy supply. T Correct energy demand predictions will serve to guarantee that procurement, investment, and policy decisions are made correctly [3].

The relationship between energy consumption and CO_2 emissions in the study of economic development and market capitalization has included measurement through panel data analysis. Financial development is the most important indicator of the general economic situation of countries. As financial development is an important source of information on the amount and quality of funds that can be invested, the outcomes achieved in the study will contribute to the policy created, by responding to the levels of energy consumption and CO_2 emissions associated with economic and financial development. The impact of financial development in developing countries on their energy use and CO_2 emissions has not yet been adequately examined in the literature. For this reason, while analyzing the relationships among energy consumption, CO_2 emissions, and economic development, financial development is added into the equation. We attempt to determine the relationship between financial development, economic growth, CO_2 emissions, and energy consumption through conducting panel data analysis considering 13 developing countries.

This study, unlike the existing literature, attempts to analyze the environmental effects of financial development, which is a result of capital accumulation for all developing countries whose data is accessible. Moreover, we aim to contribute to the literature with the motivation of obtaining strong and efficient econometric results through conducting panel data analysis in countries with similar economic structures. To achieve the stated objectives, taking into account the cross-sectional dependence problem, heteroskedasticity, serial correlation, and multi-structural breaks, we employ the second-generation panel unit root test, Westerlund Cointegration Test, and PMG-MG estimators.

This study was carried out considering 13 countries for which uninterrupted data could be obtained from the Morgan Stanley developing countries index in the years between 1993 and 2018. Our main aim was to determine whether the developing countries have created carbon emissions parallel to their increasing financial development and economic growth.

The remainder of this study is organized as follows: In Section 2, we provide an empirical literature review. In Section 3, we present our econometric model and the used data set. Section 4 details our empirical results and findings. Finally, Section 5 provides policy implications and our conclusions.

2. Literature Review

Thus far, numerous studies have examined the relationships between financial development, energy consumption, and CO_2 emissions. Each of these studies had different focuses. However, their main focus has been the affiliation of GDP to energy consumption or CO_2 emissions as indicators of economic development. In a study considering developed countries, Stern [4] concluded that, in the post-war period in the USA, the GDP and energy use relationship showed linear cointegration between the two variables. In [5], it was found that variables such as long-term energy use and economic development were cointegrated with each other in Canada. In a similar manner, ref. [6] in the G7 countries, Stavros [7] in the U.S., ref. [8] in the U.S., ref. [9] in Europe, ref. [10] in Switzerland, and ref. [11] in Canada, Italy, the U.S., the U.K., and France, have decided that linear relationships exist between economic development and energy consumption. From the studies evaluated (both those concerned with developed and developing countries) [12–19], linear relationships have been observed among energy consumption, CO_2 emissions, and economic advancement.

As for studies in which only developing countries were evaluated, ref. [20] observed a relationship between energy consumption, urbanization, and growth for the period from

1971 to 2014 in emerging markets. In [21], it was stated that renewable energy use had a beneficial and remarkable effect in 42 developing countries throughout the period covering 2002 to 2011, whereas non-renewable energy use had an adverse effect on the development; ref. [22] found a remarkable beneficial relationship between economic growth and CO_2 emissions; ref. [23] found a palpable positive effect between energy use and electricity consumption with the CO_2 emissions of Algeria in the period 1970–2010; and ref. [24] found significant relationships among the factors of economic development, pollutant emissions, and energy use in South Africa between 1965–2006. On the other hand, ref. [25] observed no relationship between economic growth and CO_2 emissions. Their study showed that CO2 emissions are not sensitive to the average growth rate. In [26], it was found that, in the early stages of the economic development, CO_2 emissions rise while, after the average income of a country reaches a certain economic level, CO_2 emissions begin to decrease.

While the studies conducted were generally based on similar relationships, ref. [27] stated that the financial variables used in a study may also have an influence on the energy use and CO_2 emissions.

Some studies have investigated CO_2 emissions and economic growth, from the point of view of the potential for investment in the energy market (see, e.g., [28–32]); however, in this study, we did not consider this subject, in order not to digress from our main subject and to show the effects of the variables mentioned more clearly.

Monetary growth has an influence on both energy consumption and CO_2 emissions, which may be evaluated as a summary of total savings and investments in the country. These effects can be summarized as follows: first, the strength of the financial structure leads to higher resource accumulation within the country. Secondly, more resources can finance investments more easily, leading to new investments. Third, foreigners who see the strong financial system in the country increase their demand to the country, as both financial fund transfer and direct investments. In conclusion, both financial and economic advancement will lead to the growth of various sectors, which may cause an escalation in CO_2 emissions in relation to the energy required and the use of energy.

Starting with [27], there have been a few studies in the literature examining the affiliation between energy consumption, economic growth, and CO_2 emissions, as well as financial development. For instance, ref. [33] discovered a beneficial and significant affiliation between all these concepts in 22 developing countries through panel data analysis in the period of 1990–2006. In [34], a positive affiliation was also discovered, in which the author used banking variables in nine European frontier economies in the period of 1996–2006. Likewise, ref. [35] concluded that monetary growth had a remarkable effect on energy consumption during 1972–2012 in Pakistan. Meanwhile, ref. [36] observed long-term relationships among energy use, financial development, CO_2 emissions, and real GDP through an ARDL bound test in Gulf Cooperation Council (GCC) countries for 1980–2011. In [37], the relationships between energy use and CO_2 emissions with GDP Growth and financial development of Sub Saharan African Countries were investigated through panel data analysis. They found a significant effect of energy consumption on economic growth and financial development between 1980 and 2008. The authors in [38] found long-term co-integration among energy use, economic growth, and financial development; moreover, in contrast to previous studies, financial development reduced energy use by increasing energy efficiency in Malaysia. In [39], the relationships between financial development and energy use in 27 EU countries were investigated, and no significant relationships were found. Furthermore, ref. [40] stated that, between the period of 1992–2004, economic and financial development have had a decreasing effect on CO_2 emissions in BRIC countries. In [41], it was stated that economic development and financial development have a mitigating effect on CO_2 emissions, based on data from 1954 to 2006 in China. In other words, as economic development and financial development increase, CO_2 emissions decrease.

3. Materials and Methods

The aim of this study is to examine the relationships between energy use, CO_2 emissions, market capitalization, and economic development by means of a panel data set considering thirteen developing countries.

$$GDP_t = \beta_1 + \beta_2 GDP_{t-1} + \beta_3 EU_t + \beta_4 CO_{2t} + \beta_5 MCAP_t + \varepsilon_t \quad (1)$$

In Equation (1):

GDP: Gross domestic product (Constant 2015 US$) is a robust indicator of economic development, widely used as a sign of whether an economy is performing well in the literature; for instance, see [42–44].

EU: Energy use (kg of oil equivalent per capita) is the most-used gauge in the literature; see, for example, [45–47].

CO_2: CO_2 emissions (kg per 2015 US$ of GDP) represent pollution in the environment; see [48–50].

MCAP: Market capitalization of listed domestic companies (% of GDP) reflects financial accumulation and development; see [51–53].

With the aim of analyzing the relationships between long-run economic growth, energy use, CO_2 emissions, and market capitalization, and utilizing yearly data taken from the WDI of World Bank (WB), we investigate these indicators in thirteen developing countries (Chile, Czech Rep., Indonesia, Korea Rep., Mexico, Malaysia, Pakistan, Peru, Philippines, Poland, South Africa, Thailand, Turkey) over the period 1993–2018.

3.1. Econometric Methodology

The analysis model is based on the dynamic framework and was used to analyze the relationships between long-run financial, economic development, energy usage, and CO_2 emissions. First, the LM test statistics of [54–56] were calculated to measure the cross-sectional dependence, followed by panel unit root tests, including the LLC test; IPS test; CIPS test; and the HK test [57–60]. Then, panel cointegration analysis based on [61] was applied, after which we established long-run coefficients through application of the method in [62].

3.2. Testing for Cross-Section Dependence

The importance of cross-section correlations of residuals were scrutinized throughout the study. The related test was executed by means of LM test statistics [55–57]. Taking the sum of squared correlation coefficients among the cross-section residuals ($\hat{u}_{it}$), attained by means of ordinary least squares [55], the LM test statistic CD_{LM1} can be calculated as:

$$CD_{LM1} = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \quad (2)$$

where $\hat{\rho}_{ij}$ corresponds to the sample estimate of the cross-section correlation among residuals. Under the null hypothesis of no cross-section correlations, fixed N, and $T \to \alpha$, the CDLM1 statistic is presents a χ^2 distribution with $N(N-1)/2$ degrees of freedom.

The test statistic CD_{LM2} is calculated as follows:

$$CD_{LM2} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T\hat{\rho}_{ij}^2 - 1). \quad (3)$$

As can be seen from the above, under the null hypothesis of no cross-section correlations with first $T \to \alpha$ and then $N \to \alpha$, the Pesaran (2004) test statistic (CD_{LM2}) is asymptotically distributed as a standard normal distribution.

The consistency of the bias-adjusted *LM* test (CD_{LMADJ}) of cross-section independence continues even simultaneously with the inconsistency of Pesaran's (2004) CD_{LM} test. Nevertheless, the legitimate power of the test LM is valid only in small sample panels. If we presume that, under the null hypothesis of no cross-section correlation with first $T \rightarrow \alpha$ and then $N \rightarrow \alpha$, then the test statistic CD_{LMADJ} would be demonstrated as follows:

$$LM_{adj} = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{(T-k)\hat{\rho}_{ij}^{2} - \mu_{Tij}}{v_{Tij}}. \quad (4)$$

3.3. Co-Integration Test

Founded on the null hypothesis of co-integration, which grants the likelihood of multi-structural breaks in not only the level, but also the trend of a co-integrated panel regression, the test in [61] requires the co-integration of variables when they are non-stationary. For this purpose, an empirical specification of our theoretical model is given below:

$$S_{it} = \propto_{ij} + \tau_{ij} t + \beta_i (M_{it}) + \omega_{it}, \quad (5)$$

where $\beta_{i,}$ are slope variables of country specific that are supposed to be constant in the time period. $\propto_{ij}$ is intercept variables of country specific. τ_{ij} is trend variables of country specific. M_i is structural breaks. The errors (ω_{it}) is calculated as follows:

$$\omega_{it} = g_{it} + \varepsilon_{it}, \quad (6)$$

$$g_{it} = g_{it-1} + \rho_i \varepsilon_{it}, \quad (7)$$

where ε_{it} has zero conditional mean. The errors are determined to stationary distribution with independent across i. The ε_{it} is supposed to be stationary distribution that has the possibility of being not only heteroskedastic, but also serially correlated.

3.4. Long-Run Coefficients

With the aim of calculating the long-run equation [63], the Autoregressive Distributed Lag (ARDL) model was applied.

The sample ARDL model is given as:

$$y_{it} = \alpha_i + \varphi_i y_{i,t-1} + \gamma_i X_{it} + \delta_i z_t + u_{it}, \quad (8)$$

for $i = 1, 2, \ldots, N$, $t = 1, 2, \ldots, T$, where x_{it} is $k \times I$ vector variables of agent-specific forcing and z_t is a vector variables of common forcing.

In this model, short- or long-run homogeneity-related variables are not allowed, due to the estimators, such as the Mean Group estimator (MG). In this paper, a panel ARDL model was used with the aim of dealing with the disadvantages of the individual ARDL models, which was calculated using the Pooled Mean Group estimator (PMG). Both of these estimators were proposed in [63]. The first sets no restriction on the long-run parameters of Autoregressive Distributed Lag specifications and derives from the individual Autoregressive Distributed Lag estimates. However, the main disadvantage of ARDL estimator is that no certain parameters are allowed to exist in the same cross-panel members. This disadvantage may be overcome by using PMG, which require to be same of the dynamic parameters. The estimator allows short-run variables, intercepts, error variances to differ separately across panel countries. In this way, short-term heterogeneity is allowed with long-term homogeneity of variables in the panel ARDL model.

In the model, which enables differences between alternative estimator specifications, tests of long-run parameter homogeneity can be executed both on their own and together. Nevertheless, it has been emphasized [61] that, in the case of panel data studies, MG and PMG estimators tend to reject excessively the homogeneity hypothesis. For this reason, the test proposed in [63] was used in this study for long-run homogeneity.

4. Empirical Findings

First, the importance of the cross-section correlations among residuals were scrutinized. In Table 1, the statistics and their corresponding probabilities are provided.

Table 1. Cross-section dependence test results.

	GDP		*EU*		CO_2		*MCAP*	
Test Statistic	**Value**	**Prob**	**Value**	**Prob**	**Value**	**Prob**	**Value**	**Prob**
CD_{LM1}	224.773 *	0.000	223.761 *	0.000	184.329 *	0.003	296.398 *	0.000
CD_{LM2}	5.381 *	0.000	5.343 *	0.000	3.041 *	0.002	9.562 *	0.001
CD_{LMADJ}	45.263 *	0.000	24.023 *	0.001	17.632 *	0.008	41.636 *	0.005

Note: * indicates cross-section dependence.

According to the CD_{LM1}, CD_{LM2}, and CD_{LMADJ} tests, the correlations among cross-sectional residuals were of great significance. Therefore, while measuring the stationarity of the series, cross-sectional dependence was allowed and panel root tests were utilized, such as the Levin, Lin, and Chu (LLC); Im, Pesaran, and Shin (IPS); Cross-Sectionally Augmented IPS (CIPS); and Hadri-Kurozumi (HK) tests [57–60].

In Table 2, upon scrutiny, each of the variables seemed to be stationary, especially the intercept and trend. Our findings, therefore, suggest that non-stationarity cannot be rejected.

Table 2. Panel unit root test results.

	$\text{LLC}_{\text{t-stat}}$		$\text{IPS}_{\text{W-stat}}$		$\text{CIPS}_{\text{stat}}$		HK	
	Intercept	**Intercept + Trend**	**Intercept**	**Intercept + Trend**	**Intercept**	**Intercept + Trend**	Z_A^{SPC} **Intercept + Trend**	Z_A^{LA} **Intercept + Trend**
GDP	−7.01 *	−9.98 ***	−7.73 **	−10.89 ***	−4.02 *	−4.59 **	11.94 *	14.81 *
EU	−4.63 **	−8.29 ***	−4.72 **	−12.80 ***	−2.98 *	−2.80 **	7.17 **	8.42 **
CO_2	−7.84 *	−9.55 **	−2.84 *	−5.74 *	−9.95 **	−10.66 ***	21.87 **	24.85 ***
MCAP	−1.04 *	−2.74 *	−1.24	−2.66 *	−2.32 *	−3.92 **	−1.01 *	11.97 **

Note: ***, **, and * imply rejection of the null hypothesis at 1%, 5%, 10% level of importance, respectively. The lag lengths were chosen using the Akaike Information Criterion. Newey–West bandwidth selection with Bartlett kernel was used for both LLC tests. The critical values for the CIPS test were obtained from [59], Table II(c) (Case III: Intercept-trend). The null distribution of the Z_A^{SPC} and Z_A^{LA} statistics was asymptotically standard normal. The Z_A^{SPC} and Z_A^{LA} null hypothesis is stationarity.

With the aim of testing the null hypothesis of co-integration, the co-integration method of [61] is equivalent to testing H_0: $\sigma_i^2 = 0$ for all i against H_1: $\sigma_i^2 > 0$ for some i.

In Table 3, it is suggested that the null hypothesis of co-integration is heavily repudiated for the no break-model and asymptotic normal distribution. Nevertheless, as incorrect exclusions of structural breaks may cause this type of test to be biased towards co-integration, the results above need to be approached carefully. The break-model, which can be interpreted to be the null hypothesis of co-integration is, at the same time, incapable of refusing an asymptomatic normal distribution. In fact, allowing both structural shifts and cross-country dependence would result in the fact that the null hypothesis of co-integration cannot be rejected at the 10% level for the bootstrapped distribution. This result implies that the variables were, in fact co-integrated, which can be clearly seen in the model.

In Table 4 below, the implications of the alternative estimates for the relationships between GDP, energy use, CO_2 emissions, and market capitalization can be seen, while imposing no restrictions; as well as those with PMG, imposing common long-run effects that constrain all of the slope coefficients and error variances to be same [62].

Table 3. Co-integration test results.

	Test	Cointegration Test
No breaks	Value	9.003
	p-value [a]	0.056
	p-value [b]	0.898 *
Breaks	Value	9.889
	p-value [a]	0.000
	p-value [b]	0.995 *

Note: The p-value [a] is based on the asymptotic normal distribution. The p-value [b] is based on the bootstrapped distribution. We used 1000 bootstrap replications. * indicates cointegration.

Table 4. Results for PMG and MG.

	PMG	MG	Hausman Test
Long-run coefficient			
GDP	0.04 *	0.02 **	7.56 *
EU	0.23 ***	0.17 **	6.55 ***
$\boldsymbol{CO_2}$	0.77 **	0.91 *	8.78 **
MCAP	0.96 **	1.04 **	3.21 **
Error correction coefficient			
Ø	−0.995 *	−0.990 *	
Short-run coefficient			
$\boldsymbol{\Delta GDP}$	0.05 ***	0.03 **	
$\boldsymbol{\Delta EU}$	−0.02 *	0.07 *	
$\boldsymbol{\Delta CO_2}$	0.04 **	0.75 **	
MCAP	0.17 *	0.21 **	
Diagnostics			
Log-likelihood	253.92	302.03	
χ^2_{SC}	7.27	9.23	
χ^2_{HE}	0.78	0.71	

Note: ***, **, and * indicate rejection of the null hypothesis at the 1%, 5%, and 10% significance levels, respectively. The maximum lags number for each variable was set at two, and optimal lag lengths were selected using the AIC. χ^2SC and χ^2HE denote the chi-squared statistics to test for a lack of residual serial correlation and homoscedasticity, respectively.

The presence of co-integration between the variables is indicated in Table 4. The negative and significant error correction coefficient indicates that there is the adjustment towards equilibrium between the variables and economic growth.

These results are from ARDL (2, 2, 2), where the corresponding lags for real income, interest rate, and exchange rate are shown in the brackets, respectively, using the Akaike information criterion as a guide.

The Hausman Test results approve the use of consistent and efficient Pooled Mean Group Estimator at the 1% significance level. Due to this fact, utilizing the Pooled Mean Group estimator seems to be more applicable, when compared to the Mean Group estimator. The results of the diagnostic test indicated the absence of any autocorrelations or heteroscedasticity in the individual equations.

5. Policy Implications and Conclusions

In the literature, econometric analyses of the effects of economic development on CO_2 emissions and environmental pollution started to gain popularity in the 1990s. However, econometric studies on the relationships between classical factors, such as economic indicators, technological developments, and political factors, as well as environmental factors such as CO_2 emissions and fossil fuel consumption, need to be further advanced. New factors may help to find new relationships to achieve a more livable and sustainable environment. At this point, the effect of financial development, strengthened by the capital accumulated over decades, on CO_2 emissions has been barely studied in the literature. Therefore, as in classical studies, on one hand, the effects of economic development on CO_2

emissions were measured while, on the other hand, the effects of financial development on CO_2 emissions were also measured.

We attempted to determine the relationships between financial development, economic growth, CO_2, emissions and energy consumption in this paper. We conducted panel data analysis considering 13 emerging countries for which we could obtain uninterrupted data in the Morgan Stanley Developing Countries index.

In the course of the study, first, the LM test statistics of [54–56] were applied to estimate the cross-sectional dependence. Following these tests, panel unit root tests—LLC, IPS, CIPS, and HK [57–60]—were applied. Then, panel co-integration analyses were executed based on the method of [61] and, as the last step, long-run coefficients were obtained using the method of [62].

We tried to determine the relationships between financial development, economic growth, energy use, and CO_2 emissions. In order to reach our goal, we carried out long-term co-integration analysis. In the related literature, there have been different results on this issue.

1. When we measured the effects of economic development on CO_2 emissions, contrary to [25,26,41], we observed significant relationships between economic growth, energy usage, and CO_2 emissions, similar to [5–13,15,17–24,34].
2. When the analysis results were examined, in terms of the effects of financial development on carbon emissions, contrary to the results obtained by scholars such as [38,40], we found that the variables were co-integrated in the long-term, in agreement with previous studies such as [33–37].
3. As a result of the specified findings, we primarily demonstrated that financial growth has a significant effect, along with economic development, on energy use and carbon emissions. Therefore, energy economists should consider the influence of financial development on these factors in the future studies.
4. The findings of our analysis demonstrated a positive sign for the coefficient between financial development and economic growth, implying that these concepts are realized with a high risk of environmental pollution. Moreover, the analysis revealed that financial development in particular accelerates the environmental pollution rate. The fact that carbon emissions are determined by financial development and economic growth is also another finding of the analysis. Therefore, policy-makers in emerging markets should take the required steps to reduce carbon emissions while increasing financial development.

We recommend policy makers consider the results of this study in the decision-making. On one hand, the energy consumption that will be caused through development of the financial structure must be met through the use of cleaner energy sources with fewer carbon emissions; on the other hand, measures should be taken to reduce existing carbon emissions.

As a result, similar studies should be conducted, based on long-term data with a higher number of developing countries. We believe that researchers should focus on the issues that arose in this study in future studies, such that the results obtained will have an even stronger effect on policy-makers.

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