

Article

# Incorporating Forests, Agriculture, and Energy Consumption in the Framework of the Environmental Kuznets Curve: A Dynamic Panel Data Approach

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**Abstract:** Based on country-specific panel data from 1990–2014 for 86 different countries, we quantify the effects of forests and agricultural land in CO<sub>2</sub> emissions, using the framework of the Environmental Kuznets Curve (EKC). The results from the dynamic panel data method reveal that forests are an important determinant in reducing CO<sub>2</sub> emissions globally, but the effects vary by region. All else constant, we estimate a 0.11% decline in CO<sub>2</sub> emissions per 1% increase in the forest area globally. However, the agricultural sector is found to be a true CO<sub>2</sub> emitter. Our study provides additional empirical evidence for the roles of forests in regulating atmospheric CO<sub>2</sub>, further reinforcing the importance of forests in global climate change policies.

**Keywords:** dynamic panel data model; Environmental Kuznets Curve; CO<sub>2</sub> emissions; economic growth; endogeneity

## 1. Introduction

While economic development brings much needed prosperity in society, it comes at costs to the environment [1]. In particular, natural resources such as forests are under continuous pressure of economic development. Deforestation is a major source of human-induced carbon emissions, second only to fossil fuel combustion. It has reduced the total available acres of forest cover and has resulted in substantial land use change around the world [2]. Non-forestry uses of land, such as harvesting timber for conversion to agricultural land, release a substantial amount of carbon into the atmosphere [3].

The past few decades have witnessed significant global efforts in sustainable development as environmental conservation has come to the forefront of international negotiations and policies. An important milestone in those efforts was the “The Reducing Emissions from Deforestation and Degradation (REDD) and Enhancing Carbon Stocks (REDD+)”, as it postulated an idea of “payment for environmental services (PES)” [4]. Under the United Nations Framework Convention on Climate Change (UNFCCC), the concept of REDD+ envisions a result-based payment system in which the countries that put efforts toward forest conservation would be rewarded for their efforts [5].

The dual roles of forests in regulating the atmospheric CO<sub>2</sub> level have been well documented. The total forest area in the world is 3999 million hectares, which acts as a primary reservoir of carbon [6]. Global forests store more than 650 billion tons of carbon, including 296 billion tons in both above- and below-ground biomass, and sequester 8.5 billion tons of CO<sub>2</sub> per year from the atmosphere [6]. On the other hand, deforestation and forest degradation account for about 11% of anthropogenic emissions,

equivalent to 5–9 Gt CO<sub>2</sub>e [7]. The UN's Intergovernmental Panel on Climate Change reports that land use, land-use change, and forestry account for around 17% of total annual global greenhouse gas emissions [8]. Over 25 years, between 1990 and 2015, carbon stocks in forest biomass decreased by about 17.4 Gt (697 million tons per year), mainly due to conversion to agriculture, settlements, and degradation of forest land [6]. This is an important oversight, given that some developing countries have increased forest carbon stock as they have transitioned from net deforestation to net reforestation in the past decade [9]. For example, over the recent period from 2010 to 2015, annual forest cover gain in China, Chile, the Philippines, and India was 1,542,000 ha, 301,000 ha, 240,000 ha, and 178,000 ha, respectively [6]. Because carbon financing in REDD+ implementation has been put forth as a mechanism for reducing atmospheric CO<sub>2</sub>, it is critically important to understand whether forests are a net carbon sink or source.

Several efforts have been made to understand the trade-offs between economic development and environmental quality. Investigating the empirical relationship between economic development and environmental quality has been a constant topic of academic research since the emergence of the seminal concept on the Environmental Kuznets Curve (EKC) [1]. The EKC approach deduces the relationship between the level of economic growth of a country or region and the level of environmental degradation measured by various environmental indicators. The EKC hypothesis states that some forms of environmental degradation are triggered by the initial phase of economic development of a region, but a subsequent increase in income in the long run would ultimately improve the environmental quality [10].

The main purpose of our study is to investigate the effects of forests, agricultural area, and energy consumption on CO<sub>2</sub> emissions worldwide. Given that the roles of forests in CO<sub>2</sub> emissions are reportedly mixed, as some studies reported that forests are a net source of carbon emissions [11], quantitative assessments of the relationships between CO<sub>2</sub> emissions and forests are necessary to understand the contributions of forests toward global CO<sub>2</sub> emission reductions. Moreover, we employ an advanced econometric estimation method that addresses both unobserved heterogeneity in the panel data and the endogeneity issue between CO<sub>2</sub> emissions and income. The results of our study are particularly relevant in the context of global climate change and resource management policies like REDD+, as those policies are primarily based on the role of forests in reducing atmospheric CO<sub>2</sub> through carbon sequestration and long-term storage.

## 2. A Brief Overview of Empirical EKC Literature

Several studies explain the underlying theoretical framework of EKC [12,13]. According to the EKC framework, at the early stages of economic growth, people pay more attention to jobs and income rather than their surrounding environment and regulations [14]. The rate of resource extraction tends to exceed the rate of resource generation. As countries prosper, people are more interested in clean air and water, and regulatory institutions become more proactive. They gradually replace production of certain pollution-intensive goods with imported products from other countries with less restrictive environmental protection laws [15]. Stringent government regulations and technical innovations in developed countries are the major factors in describing potential decreases in pollution as countries grow beyond certain levels [12,14]. Moreover, [13] stated that insufficient investment for abatement activities in the early stages of economic development generates environmental degradation. People are unable to pay for abatement and they ignore negative environmental consequences of economic growth. However, when countries accumulate enough capital stocks in the later stages, there is sufficient investment for abatement activities, putting more efforts toward reverting the relationship between pollution and economic growth.

Based on a theoretical foundation of EKC, several studies have tested the relationship between environmental degradation and income [1,16,17]. They modified the EKC hypothesis by including several socioeconomic and environmental variables: Energy consumption, population density, political factors, and trade openness ratio of a country. For example, [1] reported an inverted U-shaped

EKC relationship only for concentrations of sulfur dioxide and suspended particulates in city air. Likewise, [15] estimated a reduced-form relationship between per capita income and environmental indicators, such as urban air pollution and contamination in river basins, and found the prevalence of an inverted U-shaped EKC relationship for air and water quality, with an average turning point of \$8000 per capita income.

Some of the recent studies in empirical testing of EKC primarily focused on new and improved estimation methods and region- or country-specific geographic coverage of their analyses. Using the dynamic panel generalized method of moments technique, [18] showed the evidence of the EKC hypothesis for CO<sub>2</sub> emissions in a global data set, as well as for middle-income, and American and European countries. In [19], a symbolic regression model was utilized to investigate how the inclusion or exclusion of regions or countries could influence the relationship between CO<sub>2</sub> emissions and economic growth. The authors found that while the relationship generally followed monotonically increasing N-shaped and inverted U-shaped patterns in developed countries, the relationship was sporadic, ranging from M-shaped to inverted N-shaped, in countries in East Asia, Asia Pacific, the Caribbean, Latin America, and South Asia. Citing econometric specification issues with the traditional Granger causality test, [20] used the Rossi instability-robust causality test to understand emission and growth relationships within Middle Eastern and North African Countries. The authors found that the United Arab Emirates and Syria, two countries with drastically different economic conditions, had a striking similarity in that CO<sub>2</sub> emission reductions did not affect their income. Furthermore, [21] used a trend extrapolation and a back propagation (BP) neural network approach to investigate whether the top ten emitting countries were likely to achieve the emission targets stipulated in the Paris Climate Agreement. The authors highlighted that while some countries such as China, India, and Russia are on path to meet the targets, some top polluters such as the United States, Japan, Germany, and South Korea are likely to fall short. Similarly, [22] used provincial and territorial data starting from 1990 to 2014 to determine the relationship between environmental degradation and GDP per capita in Canada. Similar to Yang et al.'s (2015) results, the EKC relationship was not found universally. It is found to exist only at the national level and in half of the provinces and territories in Canada.

Some studies considered the rate of deforestation as an indicator of environmental degradation and estimated the relationship between economic growth and deforestation over time [16,23,24]. Due to data deficiency, [25] could not confirm the EKC relationship for both the annual rate of deforestation and total deforestation between 1961 and 1986. Along with several additional institutional and population factors, [16] developed an empirical model to investigate the EKC relationship for deforestation, and confirmed the existence of an EKC relationship for deforestation in Latin America and Africa but not in Asian countries. Similarly, [23] assessed the existence of the EKC relationship between per capita GDP and forest area clearcutting in five regions in Canada. His empirical estimation strongly rejected the existence of the EKC hypothesis for clearcutting in Canadian forests. However, [24] found evidence of the EKC relationship for deforestation in a select group of Latin American, African, and Asian countries. Except for [26], which included forestry as an independent variable, none of the other previous studies, to the best of our knowledge, examined the relationship between forest land and CO<sub>2</sub> emissions in the EKC setting.

### 3. Methods

We employ a theoretical framework of the EKC to investigate the relationship between CO<sub>2</sub> emissions, income, energy consumption, forest area, and agricultural area. The proposed model, which includes the variables of interest in the framework of EKC, is specified as:

$$CO_{2it} = \alpha_i + \gamma_t + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_4 EC_{it} + \beta_5 forest\_land_{it} + \beta_6 agri\_land_{it} + \varepsilon_{it} \quad (1)$$

where,  $t$  and  $i$  denote time period and country, respectively,  $i = 1, \dots, n$  and  $t = 1, 2, \dots, t$ . Similarly,  $\alpha_i$  refers to the unobserved country-specific heterogeneity effects, whereas  $\gamma_t$  represents the time-specific

effects. The time-specific intercept accounts for time-varying omitted variables and stochastic shocks that are common to all countries. The variable,  $CO_{2it}$ , represents per capita CO<sub>2</sub> emissions in country  $i$  at the time period  $t$ ;  $GDP_{it}$  is the per capita gross domestic product;  $EC_{it}$  is the per capita energy consumption;  $forest\_land_{it}$  represents the per capita forest area; and  $agri\_land_{it}$  refers to per capita agricultural area in country  $i$  at the time period  $t$ . Last,  $\varepsilon_{it}$  denotes the residual term.

In terms of expected signs of parameters in Equation (1), the signs of  $\beta_1$  and  $\beta_2$  should be positive and negative, respectively, as stated by the EKC hypothesis, supporting an inverted U-shaped relationship between economic growth and CO<sub>2</sub> emissions. Consistent with the previous literature [24,27,28], an inverted U-shaped relationship is hypothesized between CO<sub>2</sub> emissions and GDP of a particular country. The coefficient of energy consumption,  $\beta_3$ , is expected to be positive, since more energy consumption stimulates greater economic activities resulting in greater CO<sub>2</sub> emissions. Existing literature [29–31] reported a positive relationship between energy consumption and CO<sub>2</sub> emissions in the Middle East and North African countries. Likewise, the sign of  $\beta_4$  is expected to be negative. More forest area indicates more carbon sequestration potential of forests from the atmosphere. However, the expected sign of  $\beta_5$  is positive, as the agriculture sector is considered a CO<sub>2</sub> emitter.

Past studies used various econometric estimation approaches, predominantly panel data models, to investigate the EKC hypothesis empirically [18,32]. To account for unobserved country-specific heterogeneity in the cross-sectional time-series dataset, most of the past studies employed fixed-effect and random-effect approaches. An important oversight in existing literature is that past studies overlooked the endogeneity problem between environmental degradation and income variables, which creates simultaneity bias when estimating empirical models of EKC. There is a possibility of a two-way causality between CO<sub>2</sub> emissions and economic growth of a country [17,33,34]. An increase in economic activities triggered by higher GDP could lead to an increase in environmental degradation, such as pollution and CO<sub>2</sub> emissions. On the other hand, higher CO<sub>2</sub> emissions might negatively affect people's health and productivity, eventually negatively impacting income per capita. Moreover, GDP and CO<sub>2</sub> emissions may be jointly produced during the production process [17]. To address the issue of endogeneity, [17,34] employed an instrumental variable approach in the panel data setting. They used debt service, age dependency ratio, and an inflation index as external instruments, which are highly correlated with GDP without being directly linked to environmental degradation.

As an alternative to the external instrumental variables approach, some previous studies used a dynamic panel data approach to address the issue of endogeneity in empirical EKC models [33,35]. The dynamic panel data approach was first developed by [36], in which the auto-regressive specification is considered in a panel data setting and the model is estimated by the generalized method of moments (GMM) technique. Using appropriate lags of the dependent variable as instruments, consistent estimators are obtained by an instrumental variable approach of the parameters in the first-difference model [37]. Including additional lags addresses the endogeneity issue and unobserved country-specific heterogeneity. It also captures persistent effects of CO<sub>2</sub> emissions, since the current level of emissions could be influenced by past levels of CO<sub>2</sub> emissions. We use the dynamic panel data approach to estimate Equation (1) in which a lagged level of CO<sub>2</sub> emissions is accounted for by using the [36] GMM estimator. Equation (1) is modified into a dynamic panel data model as:

$$CO_{2it} = \alpha_i + \gamma_t + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_4 EC_{it} + \beta_5 forest\_land_{it} + \beta_6 agri\_land_{it} + \beta_7 CO_{2it-1} + \varepsilon_{it} \quad (2)$$

where,  $CO_{2it-1}$  is the first lag of CO<sub>2</sub> emissions per capita in country  $i$  in period  $t$ . The remaining variables are already defined.

The data used in the empirical estimation consists of 86 countries covering the period from 1991 to 2014. Since the main objective of our study is to examine the role of forests and agricultural land in CO<sub>2</sub> emissions, 86 countries that have at least one million hectares of forest area [38] and \$10 million of GDP [39] are selected. The country panel includes 20 African, 20 Asian, 15 Latin American, 24 European, three North American, and four other countries. The list of included countries is presented in Appendix A.

The variables, their descriptions, and data sources are presented in Table 1. Annual data on total CO<sub>2</sub> emissions per capita from energy consumption and total primary energy consumption (EC) are collected from the U.S. Energy Information Administration (EIA) [40]. The country-wise per capita GDP data (GDP) in constant 2011 international dollars are obtained from the World Bank database [41]. Similarly, data on per capita forest area (*forest\_land*) and agriculture area (*agri\_land*) in square kilometers are collected from the World Bank database. Table 2 presents the summary statistics of the data used to estimate the empirical models. The mean per capita CO<sub>2</sub> emissions per capita is 4.47 metric tons.

**Table 1.** Variables, their descriptions, and data sources.

Variable	Unit	Description	Data Source
CO <sub>2</sub>	Metric tons of CO <sub>2</sub> /person	Total CO <sub>2</sub> emissions from the energy consumption	U.S. Energy Information Administration [40]
EC	Million BTU/person	Total primary energy consumption	U.S. Energy Information Administration [40]
GDP	\$/person	GDP per capita, PPP (constant 2011 international \$)	World Bank Indicators (WDI) DataBank [41]
forest_land	Sq. km/person	Forest area per capita	World Bank Indicators (WDI) DataBank [41]
agri_land	Sq. km/person	Agricultural land per capita	World Bank Indicators (WDI) DataBank [41]

**Table 2.** Summary statistics.

Variable	No. of Observations	Mean	Standard Deviation	Min	Max
CO <sub>2</sub>	2123	4.47	4.63	0.03	26.91
EC	2123	84.00	92.22	0.27	468.39
GDP	2128	14,476.98	13,398.07	350.97	65,780.95
forest_land	2150	0.02	0.03	0	0.23
agri_land	2150	0.02	0.03	0	0.27

#### 4. Results and Discussion

Table 3 presents the results from the Arellano–Bond GMM estimation for Equation (2). All the variables are logarithmic-transformed to reduce the potential issue of heteroscedasticity. The coefficient estimates associated with most of the variables are statistically significant at the 10% confidence level or better and have expected signs. The coefficients on lagged values of per capita CO<sub>2</sub> emissions are found to be positive and statistically significant, validating the use of a dynamic panel model to estimate our empirical model. It also indicates a persistent trend in CO<sub>2</sub> emissions, suggesting that emissions in the past year have a positive impact on the level of current emissions [33]. Similarly, the Arellano–Bond test for zero autocorrelation in first differenced errors reveals that AR(1) is significant and AR(2) cannot reject the null hypothesis, suggesting that error terms are serially uncorrelated in all models [33,37]. Because Brazil, Russia, India, China, and South Africa (BRICS) are among the countries emitting the most carbon in the world (China, rank 1; India, rank 3; Russia, rank 4; Brazil, rank 13; and South Africa, rank 14) [40], we have also presented a separate model examining the EKC relationship for BRICS countries. BRICS' emissions have been increasing faster than that of other parts of the world. This is because, over the past decade, BRICS have greatly exceeded economic growth compared to the world's leading industrialized nations and are expected the similar trend in coming decades.

##### 4.1. The EKC—CO<sub>2</sub> Emissions and Economic Growth

In our data sample covering all 86 countries, a positive and statistically significant coefficient estimate for GDP and a negative estimate for GDP squared substantiates an inverted U-shape

relationship between per capita emissions and per capita income in the most forested countries in the world. Furthermore, the region-specific models' results suggest regional differences in the relationship between CO<sub>2</sub> emissions and economic growth. In the data sample of 20 African countries, consistent with the world model, an existence of an inverted U-shape relationship between per capita CO<sub>2</sub> emissions and economic growth is found (Table 3). However, in other geographic regions, results do not confirm an EKC relationship, as the estimated coefficients of GDP and GDP squared are statistically insignificant. Even though coefficient estimates associated with GDP are statistically significant for Asian countries, the signs do not meet a priori expectation, suggesting an N-shaped pattern [33].

**Table 3.** Regression results of the relationship between CO<sub>2</sub> emissions and income, energy consumption, forest, and agricultural land: 1990–2014 (86 countries).

Variable	World	Africa	Asia	Latin America	Europe	BRICS
GDP	0.77 ** (0.14)	0.94 ** (0.26)	−0.20 ** (0.08)	0.96 (0.69)	0.10 (0.31)	−0.002 (0.07)
GDP <sup>2</sup>	−0.04 ** (0.01)	−0.06 ** (0.01)	0.01 ** (0.01)	−0.04 (0.03)	−0.01 (0.02)	−0.003 (0.004)
EC	0.29 ** (0.02)	0.25 ** (0.03)	0.95 ** (0.02)	0.48 ** (0.05)	0.34 ** (0.03)	0.25 ** (0.03)
forest_land	−0.11 ** (0.05)	−0.17 * (0.10)	0.10 ** (0.03)	−0.09 <sup>a</sup> (0.05)	0.05 (0.10)	−0.08 ** (0.03)
agri_land	0.15 ** (0.06)	0.15 (0.12)	0.08 ** (0.03)	0.15 ** (0.07)	0.19 ** (0.05)	0.07 <sup>a</sup> (0.04)
L.CO <sub>2</sub>	0.44 ** (0.03)	0.50 ** (0.05)	0.06 ** (0.02)	0.38 ** (0.04)	0.65 ** (0.03)	0.05 ** (0.02)
Constant	−4.12 ** (0.66)	−4.74 ** (1.13)	−0.83 ** (0.42)	−6.11 * (3.17)	−0.14 (1.85)	−2.67 ** (0.29)
No. of obs	1942	460	496	390	527	113
No. of countries	86	20	20	16	24	5
AR(1) <sup>b</sup>	−2.87 ** [0.01]	−1.98 ** [0.05]	−2.15 ** [0.03]	−2.65 ** [0.01]	−3.71 ** [0.00]	−1.37 [0.17]
AR(2)	−0.89 [0.37]	−1.10 [0.27]	−0.14 [0.89]	−1.73 * [0.08]	−1.20 [0.23]	1.08 [0.28]
Turning point	\$15,139	\$2523				

\*, \*\* significant at 10% and 5% respectively. <sup>a</sup> significant at 12%. Values in parentheses and brackets are standard errors and *p*-values, respectively. <sup>b</sup> Arellano–Bond test for zero autocorrelation in first-differenced errors. BRICS stands for Brazil, Russia, India, China, and South Africa.

Past literature also revealed mixed findings on the EKC relationship between CO<sub>2</sub> emissions and economic growth. While [32,42] reported an inverted U-shaped relationship, [1,33] revealed either linear or N-shaped relationships between CO<sub>2</sub> emissions and GDP. Similarly, in an extensive review, [43] also concluded that, in most cases, carbon emissions have an upward linear relationship with economic growth. Carbon emissions are considered to have a global impact beyond the boundary of a country or region. The EKC relationship is only confirmed for pollutants involving local short-term costs like sulfur dioxide and other water pollutants [17], not for the accumulated stocks of waste or more dispersed costs like CO<sub>2</sub> emissions [10].

#### 4.2. CO<sub>2</sub> Emissions and Energy Consumption

The coefficient estimate of energy consumption is statistically significant and its sign is as expected. The results show that a 1% increase in the per capita total energy consumption, all else equal, leads to a 0.29% increase in CO<sub>2</sub> emissions (Table 3). Several previous studies also revealed that energy use is a

major determinant of CO<sub>2</sub> emissions in the framework of the EKC relationship [44,45]. The relationship between CO<sub>2</sub> emissions and energy consumption is consistent regardless of the region. The coefficient estimates associated with energy consumption are statistically significant with a positive value ranging from 0.25–0.95, indicating that energy consumption is one of the major sources of CO<sub>2</sub> emissions. The lowest energy consumption coefficient estimate is for African countries and the largest estimated value is for Asian countries.

This result is consistent with the expectation that higher levels of total primary energy consumption lead to more CO<sub>2</sub> emissions. Most of the earlier studies [29,46,47] also reported a positive contribution from the energy consumption variable to CO<sub>2</sub> emissions in various countries and regions. The primary energy consumption data are mostly dominated by non-renewable energy sources, particularly petroleum and other liquids, followed by natural gas and coal [48]. Energy consumption in Asia is the major source of CO<sub>2</sub> emissions, as this region is a leading petroleum oil producer, specifically the Middle East. Similarly, Southeast Asia is an important fossil fuel producer as well as a net coal-exporting region [48].

#### 4.3. CO<sub>2</sub> Emissions and Forest Area

In the world model covering 86 countries, the results support the negative relationship between forest area and CO<sub>2</sub> emissions. The coefficient of forest area is statistically significant and suggests that, all else constant, a 1% increase in the forest area results in a 0.11% decline in CO<sub>2</sub> emissions. It can be inferred that the forest sector helps reduce the overall CO<sub>2</sub> emissions throughout the world. However, this result is mixed when the analyses are extended to groups of countries by their geographic locations and economic conditions. The coefficient estimate associated with forest land is negative and statistically significant for African countries and BRICS—the group of the highest carbon emitters. The estimated coefficient for Latin American Countries is  $-0.09$ , which is marginally insignificant at the 10% level ( $p = 0.012$ ). The estimate of forest land is, however, found to be statistically insignificant in the model of European countries.

While the forest sector via deforestation is the second largest source of anthropogenic CO<sub>2</sub> emissions into the atmosphere [49], our empirical results suggest that forests play a significant role in reducing CO<sub>2</sub> emissions. An increase in forest area leads to an increase in the potential of sequestering atmospheric CO<sub>2</sub> by live trees and storing of carbon in long-lived forest products. The magnitude of the contribution of forest areas in countries emitting the most CO<sub>2</sub> like the United States, China, India, and Russia is quite high, indicating that forests in this group are a true CO<sub>2</sub> sink. Reference [48] reveals that since the 1990s, managed forests in the United States are a net carbon sink, meaning that they have absorbed more CO<sub>2</sub> from the atmosphere than they emit. In addition, [50] pointed out that recovered forest areas in the 20th century have contributed towards carbon sequestration in the United States.

Contrary to the other regions, the empirical findings indicate that forests in Asia (the result remains the same in the case of the data sample excluding China and India) have a positive contribution towards CO<sub>2</sub> emissions. Unlike other regions, carbon sink dynamics in Asian forests are complex. While Asia witnessed an almost two-fold increase in total plantation forestry in the past two decades, its distribution has been uneven across the countries. For example, about two-thirds of the total planted forests are in China [51], which store less carbon than naturally regenerated primary forests [52,53]. In many Asian countries, co-management practices in natural forests have helped increase national accounting on forest cover [51]. While natural forests provide many ecosystem benefits, their net impact as a carbon sink can be negative when old-growth forests undergo timber harvesting [52]. Selective timber harvesting is a primary source of revenue under co-management practices, such as community forestry management [54,55].

#### 4.4. CO<sub>2</sub> Emissions and Agricultural Area

The coefficient estimate associated with agricultural area (*agri\_land*) is found to be statistically significant with a positive value of 0.15, indicating that the agriculture sector is a true carbon emitter.

The positive relationship between CO<sub>2</sub> emissions and agricultural area is quite robust across the geographical regions. Agricultural area positively contributes to CO<sub>2</sub> emissions, except for African countries in which the coefficient estimate is not statistically significant. [48] reports that 9% of total greenhouse gas emissions in 2015 were emitted from the agriculture sector. Climate smart agriculture (CSA) is a recent approach introduced to transform and reorient agricultural development towards reducing and removing greenhouse gas emissions. Various international organizations including Food and Agriculture Organization (FAO) and the World Bank have supported various projects and programs in CSA in various countries, including China, Uruguay, Mexico, and Senegal [56,57]. Such projects are likely to have long-term impacts on reducing carbon emissions and mitigating global climate change.

#### 4.5. Policy Implications

Forests and agriculture are considered to be crucial components of the global climate policy. Without reducing deforestation and forest degradation, the two degree centigrade (or 450 ppm of CO<sub>2</sub>) climate change target, as proposed by the Paris Agreement, cannot be realized [58]. Therefore, REDD+, which accounts for the carbon sink characteristic of forests, remains the forefront climate policy and billions of dollars have been channeled for REDD+ [5]. REDD+ creates financial incentives for the carbon stored in forests and our findings further validate the applicability of the REDD+ program, particularly in the African continent. Since REDD+ is designed for developing countries, the program can help promote economic prosperity and climate change resilient ecosystems in Africa and Latin America.

There will be nine billion people by 2050 and to feed them, agricultural production must increase by 60%. It is suggested by [6] that about 80% of production increase will come from intensification and another 20% from extensification. Therefore, crop land expansion will remain the largest driver of forest loss through to 2050 [6]. Although agricultural extensification increases the share of agriculture emissions, selective extensification could save approximately 22 Gt CO<sub>2</sub> by 2050, compared with a business-as-usual approach [59]. Therefore, wise land use planning and a coordinated approach between government departments and the private sector within a country could be crucial for reducing emissions levels from the agricultural sector.

## 5. Conclusions

The EKC framework is used to examine the empirical relationship between CO<sub>2</sub> emissions, forest area, agricultural area, and energy consumption in 86 different countries from around the world. Our results support the existence of an inverted U-curve relationship between CO<sub>2</sub> emissions and economic growth at the world level, confirming the EKC hypothesis on CO<sub>2</sub> emissions, but the results vary by region. Energy consumption and agricultural land area are found to have a positive relationship with CO<sub>2</sub> emissions, indicating that both sectors positively contribute to atmospheric CO<sub>2</sub> emissions.

All else constant, on average, increasing the per capita total energy consumption by 1% increases CO<sub>2</sub> emissions by 0.29%. Since most of the global and regional energy sources are non-renewable, this relationship is consistent in all regions. Replacing this energy source with renewable energy may improve the situation. Similarly, increasing agricultural area by 1% increases CO<sub>2</sub> emissions by 0.15%. However, unlike the relationship between CO<sub>2</sub> emissions and energy, the relationship with agricultural area is not uniform and is more pronounced in Europe (0.19%) than in other parts of the world. This result indicates that the agricultural sector in Europe is more commercialized and mechanized, needing more farm inputs and thus becoming more emissions-intensive.

As expected, forestland is found to be a means of reducing atmospheric CO<sub>2</sub> emissions. Our results suggest that, at a global level, increasing forest area by 1% results in a 0.11% reduction in CO<sub>2</sub> emissions. However, the results vary from one geographic region to another, with increasing forest area more beneficial in Africa than in other parts of the world.



REDD+ is in place as a mechanism for reducing atmospheric CO<sub>2</sub> emissions. Billions of dollars are channeled to developing countries for REDD+. As noted, increasing forest area is not equally beneficial in all countries and our study provides insight into where conserving forests is more beneficial for carbon sequestration. However, our study is purely carbon-centric and has not considered non-carbon benefits. A more comprehensive analysis is necessary to consider all carbon and non-carbon benefits.

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## Appendix A

Countries included in the empirical model:

**Africa:** Angola, Botswana, Ivory Coast, Cameroon, Congo, Democratic Republic of the Congo, Equatorial Guinea, Ethiopia, Gabon, Ghana, Guinea, Kenya, Mozambique, Nigeria, Senegal, South Africa, Sudan, Tunisia, Uganda, Zambia.

**Asia:** Australia, Bangladesh, Cambodia, China, People's Republic of Korea, Georgia, India, Indonesia, Iran, Japan, Kazakhstan, Malaysia, Nepal, New Zealand, Pakistan, Papua New Guinea, Philippines, Sri Lanka, Thailand, Turkey, Turkmenistan, Uzbekistan, Vietnam.

**Latin America:** Argentina, Bolivia, Brazil, Chile, Columbia, Costa Rica, Cuba, Ecuador, Guatemala, Honduras, Morocco, Panama, Paraguay, Peru, Uruguay, Venezuela.

**Europe:** Austria, Belarus, Bulgaria, Czech Republic, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom.

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