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Effect of Deforestation on Climate Change: A Co-Integration and Causality Approach with Time Series

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Abstract: Climate change is one of the greatest threats of the 21st century due to its global economic, social, and environmental causes and consequences, which affect developing countries to a greater extent. It is worrying that climate models project a temperature increase of more than 2 °C if the current trend in emissions continues, so it is necessary to progressively reduce the annual flow of emissions from approximately seven tons to two tons per capita in the next 40 years. In this sense, this research is aimed at evaluating the effect of deforestation on climate change in Ecuador between 1990–2020, based on data from the Food and Agriculture Organization of the United Nations, for which control variables were added (livestock and agriculture). The Johansen co-integration test, a VAR Model, a VEC Model, and Granger causality were estimated to examine the short-term and long-term relationships and the direction of causality of the variables. The results showed that deforestation does not directly affect climate change; however, it does so indirectly as the existence of a short- and long-term relationship between the variables included in the model was determined. In addition, a causal relationship was determined that goes from agriculture to deforestation and in conjunction with livestock and climate change. It is worrying that variations in climate change occur in the short term because it is in danger to comply with the objectives proposed at the global level regarding climate change. Finally, intensive reforestation is recommended in conjunction with public and educational institutions, as well as the implementation of green buildings. In addition to this, government support in terms of credits, subsidies, training, and technology allow the emission of polluting gases to be reduced as much as possible.

Keywords: climate change; deforestation; time series; livestock; agriculture

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1. Introduction

2020 was the year of record temperatures and increasing climate change catastrophes such as floods, droughts, storms, wildfires, and locust swarms. These phenomena have an economic cost of billions of dollars, in addition to the suffering they cause in ecosystems and societies. Between 2000 and 2019, Puerto Rico, Myanmar, and Haiti were the countries most affected by extreme weather events. Globally 475,000 people died as a direct consequence of more than 11.000 extreme weather events, and the economic losses were about 2.56 billion dollars [1]. The years between 2015 and 2019 were the warmest since 1880, as global temperatures in 2019 were determined to be 0.95 °C above the 20th-century average. It is estimated that if the temperature increases by 2.5 °C (which will probably happen around 2050), climate change will increase the cost of Latin America and the Caribbean between 1.5% and 5% of current GDP, and in the case of Ecuador, a reduction in GDP of 19.4%.

Ecuador contributes less than 1% of greenhouse gas emissions worldwide [2,3]; however, the impact of climate change in the country is quite devastating compared to the countries that emit a greater amount of polluting gases. Despite this, the country is committed to generating policies, programs, and projects that contribute to limiting the rise in temperature by up to 1.5 °C [2,3]. In this context, the Food and Agriculture Organization of the United Nations (FAO) indicates that the country is at the limit of temperature rise [4]. Therefore, the average value of the temperature variation during the period 1990 to 2020 is 1.33 °C, which generates great concern as, according to the scenarios, the objectives proposed in the Paris Agreement could not be met.

In this sense, studying climate change has become a fashionable topic today and in relation to deforestation, which represents approximately 23% of global GHG emissions, which is more than the entire transport sector [1]. Thus, forests have a double effect on the environment, especially on climate change. On the one hand, when trees are cut, they emit CO_2 that affects the variability of climate change. Similarly, the existence of a greater number of forests on the planet helps mitigate climate change, because forests act as sinks for polluting gases.

Many studies attribute the accelerated pace of climate change to the industrial revolution as man-made; however, before this event, the already existing variability of the climate was due to natural causes such as the eruption of volcanoes, the Earth's tilt, and solar variability. In addition, it is an environmental problem of greater relevance in our time with potential and drastic consequences for both society and the ecosystem [5]. The effects that scientists predicted in the past regarding climate change are happening, i.e., loss of sea ice, the accelerated rise in sea level, and more intense heat waves, which generate concern on the part of governments and world organizations [6]. Considering the serious consequences of climate change both in the economy and in the environment, it is very necessary to analyze the causes that generate this phenomenon, in this way to have a clearer framework, and give a perspective for companies and the government so that they can adopt techniques, strategies, and policies for the well-being of the economy, people, and companies.

Empirical studies linking deforestation with climate change are scarce. However, Panday et al. [7] mention that deforestation can substantially alter climate variability and generate warmer future climate projections with greater probabilities of droughts and fires. Likewise, the World Conservation Organization comments that if more trees are planted and forests are protected, the impact of climate change can be reduced as carbon is maintained in forests and the new trees will absorb CO_2 from the atmosphere. Similarly, Kristjanson [8] mentions that by losing the battle against deforestation, we are also losing a fundamental opportunity to mitigate climate change. Likewise, Silva et al. [9] indicate that the jungle has control over the climate and that the lack of actions to control the removal of natural vegetation increases deforestation, causing large changes in temperature and rainfall variations over time.

2. Materials and Methods

As Ecuador is a country with high vulnerability to the effects of climate change, this scenario generates great concern regarding the social and economic wellness of the country. In this sense, the main objective of this research is to estimate the effect of deforestation on climate change in Ecuador from the period 1990 to 2020 [2]. To fulfill the objective, the data available from the FAO [1] were used. Based on this, an econometric analysis was carried out using co-integration techniques to estimate a Vector Autoregressive Model (VAR) and Vector Error Correction (VEC) model that allowed establishing long-term and short-term relationships, respectively. Finally, the existence of causality between the variables was determined. It is important to emphasize that the econometric strategy used is what differentiates this research from existing studies because there are no studies in Ecuador that relate the variables included in the model, where deforestation and climate change are issues of interest.

2.1. Data for the Econometric Model

For the development of the following investigation, data from four variables were used. The explained variable is climate change, represented by the average temperature variation, while the explanatory variable corresponds to deforestation, represented by the production of sawn wood. To give reliability to the model, two control variables were added: livestock and agriculture. In addition, a dichotomous variable was included to capture the effect of dollarization in the country that occurred after the 1999 crisis, as it must be considered that when the economy stagnates, it affects the different economic activities, which are mainly emitters of polluting gases that cause variations in climate change. The data used in this research comes from the FAO for the years between 1990 and 2020. Below, Table 1 details each of the variables used in the econometric model.

Table 1. Description of the variables used in the econometric model.

Variable Type	Variable and Notation	Unit of Measurement	Data Source	Definition
Dependent	Average temperature variation (vt)	°C	FAO	It is the change in average surface temperature with respect to a reference climatology, corresponding to the period 1951–1980. In other words, it is how much the temperature has varied in each of the years with respect to the reference period.
Independent	Sawn timber production (lpma)	Cubic meters	FAO	Wood that has been produced from round wood, either longitudinally or through a chipping process, from both coniferous and non-coniferous species. This includes planks, joists, joists, planks, and battens, both planned and unplanned. The variable was transformed to logarithms.
Control variable	Livestock (lpgv)	Tons	FAO	Bovine meat, fresh, chilled, or frozen, with bone. Common trade names are beef and veal. The variable was transformed to logarithms.
Control variable	Value of Agricultural Production (lvpa)	Dollars	FAO	Crop statistics are recorded for 173 commodities, covering the following categories: Primary Crops, Primary Fiber Crops, Cereals, Coarse Grains, Citrus, Fruits, Jute Jute-Like Fibers, Oil Cake Equivalent, Primary Oil Crops, Pulses, Roots and tubers, Tree Nuts, Vegetables, and Melons. The variable was transformed to logarithms.

2.2. Econometric Strategy

To analyze the effect of deforestation on climate change in Ecuador, co-integration techniques were used for time series from a period of 1990 to 2020. First, a baseline regression is started, taking as a reference the study by Panday et al. [7], whose statement is formalized in Equation (1).

$$vt_t = \beta_0 + \beta_1 lpma_t + e_t \quad (1)$$

To determine what other variables cause changes in climate change in Ecuador, a new model is presented that includes two control variables: livestock and agriculture, including the dummy variable. The formalization of the model is presented in Equation (2).

$$vt_t = \beta_0 + \beta_1 lpma_t + \beta_2 lpgv_t + \beta_3 lvpa_t + \beta_4 dummy_t + e_t \quad (2)$$

where vt represents the average temperature variation, $lpma_t$ is the logarithm of sawn timber production, $lpgv_t$ indicates the logarithm of livestock, $lvpa_t$ represents the logarithm of the value of agricultural production, $dummy_t$ is the dummy variable that represents the structural change, and finally, e_t is the error or disturbance term. The subscript $t = 1990 \ldots 2020$, indicates the time, in this case, annual data.

To prevent the results from being biased and inconsistent, it is very important first to apply diagnostic tests: multicollinearity, normality, heteroskedasticity, and autocorrelation, using an Ordinary Least Squares (OLS) model. The multicollinearity test will be performed using the Variance Inflation Factor (VIF) method, which establishes that VIF values greater than ten determine the presence of multicollinearity. Likewise, Shapiro et al. [10] were used for the normality test to verify if the errors are normally distributed, for this, the value of Prob > z must be greater than 0.05. Then, the heteroscedasticity test is estimated based on White's assumptions [11], where the existence of heteroscedasticity problems is detected by reviewing the P values, if this value is greater than 0.05, it is determined that there is no heteroscedasticity. Once the heteroskedasticity test has been applied, the presence of autocorrelation is determined using the Durbin and Watson statistic [12], which tests the value of Prob > F greater than 0.05 to rule out autocorrelation. The dummy variable takes the value zero before 1999 and the value one after 2000.

Prior to estimating co-integration, it was necessary to verify the stationarity of the variables. For this, the Dickey and Fuller [13] and Phillips and Perron [14] tests were used, which test the null hypothesis that the unit root problem exists in the series, so the variable is non-stationary. It is determined that there is a unit root when the calculated value is less than the critical value. In this case, it is necessary to differentiate the variables to personalize the series, a very important requirement to check co-integration.

Consecutively, to verify the equilibrium relationship in the long run. First, it is necessary to determine the number of optimal lags of the variables through the information criterion of Akaike [15]. Based on the above, a VAR was estimated under the concept of the Johansen co-integration test [16]. The formal specification of the model is observed in Equations (3)–(6).

$$\Delta vt_t = \beta_0 + \sum_{i=t}^{N} \Delta\beta_1 lpma_{t-i} + \sum_{i=t}^{N} \Delta\beta_2 lpgv_{t-i} + \sum_{i=t}^{N} \Delta\beta_3 lvpa_{t-i} + \sum_{i=t}^{N} \Delta\beta_4 vt_{t-i} + \beta_5 dummy_t + E_t \quad (3)$$

$$\Delta lpma_t = \beta_6 + \sum_{i=t}^{N} \Delta\beta_7 lpgv_{t-i} + \sum_{i=t}^{N} \Delta\beta_8 lvpa_{t-i} + \sum_{i=t}^{N} \Delta\beta_9 vt_{t-i} + \sum_{i=t}^{N} \Delta\beta_{10} lpma_{t-i} + \beta_{11} dummy_t + E_t \quad (4)$$

$$\Delta lpgv_t = \beta_{12} + \sum_{i=t}^{N} \Delta\beta_{13} lvpa_{t-i} + \sum_{i=t}^{N} \Delta\beta_{14} vt_{t-i} + \sum_{i=t}^{N} \Delta\beta_{15} lpma_{t-i} + \sum_{i=t}^{N} \Delta\beta_{16} lpgv_{t-i} + \beta_{17} dummy_t + E_t \quad (5)$$

$$\Delta lpva_t = \beta_{18} + \sum_{i=t}^{N} \Delta\beta_{19} vt_{t-i} + \sum_{i=t}^{N} \Delta\beta_{20} lpma_{t-i} + \sum_{i=t}^{N} \Delta\beta_{21} lpgv_{t-i} + \sum_{i=t}^{N} \Delta\beta_{22} lvpa_{t-i} + \beta_{23} dummy_t + E_t \quad (6)$$

For simplicity, Equations (3)–(6) will serve to estimate the VEC Model, to which we will add the lagged error term as an additional independent variable. If the error coefficient turns out to be significant, it is concluded that there is a short-term equilibrium between the variables. The VEC model is formalized in Equations (7)–(10).

$$\Delta vt_t = \beta_0 + \sum_{i=t}^{N} \Delta\beta_1 lpma_{t-i} + \sum_{i=t}^{N} \Delta\beta_2 lpgv_{t-i} + \sum_{i=t}^{N} \Delta\beta_3 lvpa_{t-i} + \sum_{i=t}^{N} \Delta\beta_4 vt_{t-i} + \beta_5 dummy_t + \Delta\beta_6 E_{t-1} + E_t \quad (7)$$

$$\Delta lpma_t = \beta_7 + \sum_{i=t}^{N} \Delta\beta_8 lpgv_{t-i} + \sum_{i=t}^{N} \Delta\beta_9 lvpa_{t-i} + \sum_{i=t}^{N} \Delta\beta_{10} vt_{t-i} + \sum_{i=t}^{N} \Delta\beta_{11} lpma_{t-i} + \beta_{12} dummy_t + \Delta\beta_{13} E_{t-1} + E_t \quad (8)$$

$$\Delta lpgv_t = \beta_{14} + \sum_{i=t}^{N} \Delta\beta_{15} lvpa_{t-i} + \sum_{i=t}^{N} \Delta\beta_{16} vt_{t-i} + \sum_{i=t}^{N} \Delta\beta_{17} lpma_{t-i} + \sum_{i=t}^{N} \Delta\beta_{18} lpgv_{t-i} + \beta_{19} dummy_t + \Delta\beta_{20} E_{t-1} + E_t \quad (9)$$

$$\Delta lpva_t = \beta_{21} + \sum_{i=t}^{N} \Delta\beta_{22} vt_{t-i} + \sum_{i=t}^{N} \Delta\beta_{23} lpma_{t-i} + \sum_{i=t}^{N} \Delta\beta_{24} lpgv_{t-i} + \sum_{i=t}^{N} \Delta\beta_{25} lvpa_{t-i} + \beta_{26} dummy_t + \Delta\beta_{27} E_{t-1} + E_t \quad (10)$$

Finally, the causality test proposed by Granger [17] was used, which determines if one time series can predict another; that is, that an event A is caused by an event B, and vice versa. However, it should be clear that there is unidirectional and bidirectional causality. If A's behavior Grangerically causes B's behavior, the relationship is said to be unidirectional. If, on the other hand, the behavior of B predicts the behavior of A, a bidirectional relationship is said to exist. The formal representation is presented in Equation (11).

$$\Delta vt_t = \beta_0 + \beta_1 \sum_{i=t}^{N} lpma_{t-i} + \sum_{i=t}^{N} \Delta Z_{t-i} + \beta_3 \sum_{i=t}^{N} \varepsilon_{t-i} + \varepsilon_t \quad (11)$$

where Δvt_t is the average temperature variation in year t, $lpma_{t-i}$ is the logarithm of sawn timber production in year $t - i$, ε_{t-i} is the error term in year $t - i$, ΔZ_{t-i} represents the control variables, livestock, and the value of agricultural production.

3. Results

The results showed that deforestation does not directly affect climate change; however, it does so indirectly as the existence of a short-term and long-term relationship between the variables included in the model was determined. In addition, a causal relationship was determined that goes from agriculture to deforestation and in conjunction with livestock and climate change. It is worrying that variations in climate change occur in the short term because it is in danger to comply with the objectives proposed at the global level regarding climate change.

Table 2 shows the descriptive statistics that correspond to the variables included in the econometric model. This includes the mean values, the standard deviation, the minimum, and maximum values, and the total number of observations. The temperature variation is, on average, 0.61 °C, and the average production of sawn wood is 1.3 million tons during the analyzed period. It should be noted that in Ecuador, the increase in temperature has remained below 1.5 °C, as proposed in the Paris Agreement approved in 2015. The minimum and maximum values range between −0.07 °C and 1.33 °C, respectively. However, it is a value that is close to the target value and should be a concern not only for governments but also for the population in general.

Table 2. Descriptive statistics of the variables.

Variable	Obs	Mean	Standard Deviation	Min	Max
vt	31	0.614	0.326	−0.072	1.335
lpma	31	1,348,716	0.58	1,218,587	145,474
lpgv	31	1,215,578	0.28	11,513	1,249,874
lvpa	31	1,552,096	0.219	1,499,342	1,581,887

3.1. Stationarity

Regarding the results of the diagnostic tests, it was established that the model does not present problems of multicollinearity, normality, heteroscedasticity, or autocorrelation. Prior to estimating the short-term and long-term relationships, it was necessary to determine the stationarity of the variables or the presence of a unit root, for which the Dickey and Fuller [13] test was applied to determine the order of integration of the variables. Table 3 shows the results of the test, which allowed us to determine that the model has unit root problems. Therefore, the first differences were applied to all the variables to eliminate the trend effect, resulting in the variables having an order of integration I(1). It is worth mentioning that the average temperature variation and sawn wood production did not need to be differentiated as their calculated value was already greater than their critical values. However, we proceeded to extract the first differences from these variables as, for econometric purposes, all the variables must have the same order of integration.

To ratify the results obtained in the Dickey and Fuller [13] test, the test proposed by Phillips and Perrón [14] is carried out, which has the same procedure as the previous test. To determine the presence of a unit root, it must be taken into account that the calculated value must be less than the critical value. On the contrary, this test determines the existence of a unit root for all the variables included in the model, so first, differences are taken to personalize the variables. The results corroborate what was shown by Dickey and Fuller [13]; that is, the variables have an order of integration I(1), which are presented in Table 4.

Table 3. Dickey and Fuller test.

Variables	Levels				First Differences I(q)				
	Calculated Value	Critical Values			Calculated Value	Critical Values			
		1%	5%	10%		1%	5%	10%	I(1)
vt	−4510	−3716	−2986	−2624	−7770	−3723	−2989	−2625	I(1)
lpma	−3064	−3716	−2986	−2624	−7902	−3723	−2989	−2625	I(1)
lpgv	−3170	−3716	−2986	−2624	−4371	−3723	−2989	−2625	I(1)
lvpa	−1783	−3716	−2986	−2624	−9165	−3723	−2989	−2625	I(1)

Table 4. Phillips and Perron test.

Variables	Levels				First Differences I(q)				
	Calculated Value	Critical Values			Calculated Value	Critical Values			
		1%	5%	10%		1%	5%	10%	I(1)
vt	−24,775	−17,540	−12,660	−10,300	−31,670	−17,472	−12,628	−10,280	I(1)
lpma	−15,142	−17,540	−12,660	−10,300	−37,016	−17,472	−12,628	−10,280	I(1)
lpgv	−3209	−17,540	−12,660	−10,300	−24,630	−17,472	−12,628	−10,280	I(1)
lvpa	−2334	−17,540	−12,660	−10,300	−44,858	−17,472	−12,628	−10,280	I(1)

3.2. Long-Term Relationship between the Variables

Once the stationarity of the variables was verified, the long-term equilibrium relationship was verified, for this, firstly, the length of the lag is determined based on the information criterion of Akaike [15], whereby it is determined that the optimal choice of lags is two. Subsequently, Table 5 shows the results of the VAR model, determined by the Johansen test [16], which indicates the number of co-integration vectors that exist in the proposed econometric model. In this sense, the existence of three co-integration vectors is established, which means that there is a long-term relationship between the variables. Then, although the variables grow or fall, they do so in a synchronized manner and maintain said relationship over time. The long-term relationship between the variables implies that variations in wood production, livestock, and agricultural production cause changes in the mean temperature variation in the long term.

Table 5. Johansen vector co-integration test.

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistics	5% Critical Value
0	20	56.5684	-	53.3753	47.21
1	27	67.7238	0.5367	31.0646	29.68
2	32	77.1816	0.4791	12.1490 *	15.41
3	35	82.1512	0.2902	2.2097	3.76
4	36	83.2561	0.0734		

The asterisk (*) indicates the existence of co-integration vectors.

A long-term relationship between deforestation and climate change implies that the felling of trees in the country will generate increases or decreases in the average temperature variation over time, which will be reflected in rising sea levels, more intense heat waves, shrinking glaciers, and changes in plant and animal habitats, ultimately triggering problems such as increased poverty, crop failure, food insecurity, in general economic, social, and environmental problems. It is important to keep in mind that when trees are cut down, they emit large amounts of CO_2 emissions that end up altering the normal variability of the climate.

It is important to recognize that climate change is a challenge that puts the development and well-being of the population at risk; therefore, it should be managed and worked together with civil society to stop climate change in time, and with this, the serious consequences that this phenomenon brings with it would be placated, which will negatively affect future generations.

Regarding the impact of livestock, it is determined that this sector has a long-term relationship with climate change as it is recognized that livestock activities emit a large number of greenhouse gases, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which contribute significantly to climate change [18]. Livestock is one of the predominant economic activities in Ecuador, which implies a very important contribution of this sector to the economy; however, livestock production remains highly unsustainable, causing threats to the environment because its activity increases the level of pollution and greenhouse gases, which, as already mentioned, aggravate the problems regarding climate change. On the other hand, González et al. [19] mention that beef, in addition to being an important source of protein, also contributes to global warming and climate change. In the same way, Swann et al. [20] find that the transition from natural forest to pasture and agricultural crops will create warmer and drier atmospheric conditions in some countries of the world.

Agriculture is also part of the contributing factors to climate change, according to the results obtained in the present investigation. It is determined that, like livestock, the agriculture sector contributes in a synchronized way to temperature variations. The use of chemicals is of great importance in the agricultural sector, and its excessive use alters the existence of polluting gases in the environment and this, in turn, causes greater absorption of UV rays and terrestrial heat. Therefore, Wheeler et al. [21] argue that agricultural production based on the excessive use of pesticides has the consequence of positively increasing perceptions of the risk that climate change implies. Likewise, Mihiretu et al. [22] mention that in agriculture, an increase in temperature and a decrease in rainfall over time are associated with excessive exploitation of natural resources and poor management of land and water use, which generates a decrease in yields of crops and livestock.

3.3. Short-Term Relationship between the Variables

Table 6 presents the results of the VEC. The *cel1* statistic collects the lagged errors for each of the model variables. The existence of a short-term relationship is determined based on the *cel1* statistic, which is statistically significant, and indicates that there is a short-term relationship between the variables used in the model because the value of Z is greater than two, and also the value of $P > z$ is less than 0.05, reasons why it is stated that there is a short-term balance between wood production, pesticide use, livestock, emissions of CO_2 with the average variation of temperature. A short-term relationship between deforestation and climate change should generate greater concern from world organizations, national governments, and society, in general, as the impacts of deforestation on climate change are immediate. Therefore, the intervention of policymakers must be urgent, directing the actions of the national government to implement policies and strategies in the sectors of forestry, livestock, agriculture, and the reduction of CO_2 emissions. These results allow us to establish that climate change in Ecuador will cause negative effects sooner than is thought, and not only in the long term as has been historically predicted.

Table 6. Result of the short-term VEC model.

beta	Coef.	Std. Err.	*z*	*P* > *z*	95% Conf
vt	1	.	.	.	.
lpma	−0.226	0.047	−4.79	0	−0.319
lpgv	1749	0.207	8.46	0	1344
ipa	−0.055	0.005	−11.41	0	−0.064
cel1	−1238	0.101	−12.25	0	−1436
_cons	−14,561	.	.	.	.

The existence of a short-term relationship between deforestation and climate change is explained by the contiguous behavior that trees have when they are cut; they not only absorb CO_2 from the environment, but that stored carbon returns to the atmosphere once the trees are felled, causing temperature increases [23]. Therefore, the contribution of deforestation to climate change is substantial as the felling of forests increases the amount of CO_2 in a short period of time, and this, in turn, generates an increase in temperatures. As deforestation has an immediate impact on climate change, not being able to combat climate change is put at risk as there would not be enough time to stop this phenomenon as much as possible. Therefore, climate change should become one of the main issues to be addressed by national governments and international organizations as it is a problem that not only harms the country or nation that generates a greater emission of polluting gases but also the whole world.

Consequently, an increase in the global average temperature is capable of generating great impacts on ecosystems, such as sea level rise due to the melting of continental waters that could also threaten coastal areas, increased torrential rains and prolonged droughts, alteration of biological cycles, endangering freshwater reserves and the subsistence of animal and plant species, intensification of floods and droughts, increase in pests and fires due to heat waves [24].

Finally, it should be emphasized that it was not possible to carry out a more extensive contrast in terms of short-term relationships as no empirical evidence was found that can support or refute the results found in this investigation, especially for the control variables.

3.4. Causality

The Granger causality test was used [17], through which it is determined whether one time series can predict another, both unidirectionally and bidirectionally. The causal relationships that show results lower than 0.05 in the $Prob > chi^2$ statistic allow us to appreciate the causal relationship that exists between the variables exposed in the econometric model. Table 7 shows the results of the causality test.

There is unidirectional causality that goes from the value of agricultural production to the production of sawn wood, while the independent variables used in the model jointly cause variations, either positive or negative, in Ecuadorian deforestation. Regarding these results, the accelerated and sustained growth of the population has been a key determinant so that the agriculture sector also grows in the same proportion because when there is a greater demand for food, producers are forced to produce more and, therefore, need larger extensions of land to be able to meet the growing demand, this situation being a cause to deforest and acquire new agricultural land.

Although, according to Calderón et al. [25], it is important to recognize that the increase in arable land is not intended precisely to feed the population, but for the production of fodder, legumes, and pastures for feeding livestock, which is worrying as there is an inclination to excessive consumption of meat, but not to a diet based on fruits and vegetables. Foguesatto et al. [26] indicate that the adoption of sustainable agriculture practices can mitigate the effects of climate change and, at the same time, minimize the degradation of natural resources and increase food production. It is considered that the CO_2 emissions that are emitted when cutting down the trees are the ones that directly affect climate change, and not deforestation as such, which is demonstrated in these findings.

Table 7. Granger causality.

Equation	Excluded	Chi2	df	prob > chi2
dvt	dlpma	0.721	two	0.697
dvt	dlpgv	4.991	two	0.082
dvt	dlvpa	0.321	two	0.852
dvt	dummy	2.686	two	0.261
dvt	ALL	11.182	8	0.192
dlpma	dvt	1.712	two	0.425
dlpma	dlpgv	0.638	two	0.727
dlpma	dlvpa	12.27	two	0.002
dlpma	dummy	3.128	two	0.209
dlpma	ALL	17.946	8	0.022
dlpgv	dvt	5.321	two	0.07
dlpgv	dlpma	9.162	two	0.01
dlpgv	dlvpa	3.515	two	0.172
dlpgv	dummy	8.541	two	0.014
dlpgv	ALL	21.171	8	0.007
dlvpa	dvt	1.505	two	0.471
dlvpa	dlpma	2.125	two	0.346
dlvpa	dlpgv	8.596	two	0.014
dlvpa	dummy	0.769	two	0.681
dlvpa	ALL	14.071	8	0.08

In addition, deforestation, individually and in conjunction with climate change and the agriculture sector, are causing variations in livestock. It is clear that deforestation affects the increase in land used for livestock. Exactly the same thing happens with agriculture; as there is a greater demand for meat products from livestock, a greater extension of land will have to be available to be able to dedicate themselves to raising these specimens, deforestation being the way, which in turn generates positive effects in the livestock sector. Furthermore, there is evidence of unidirectional causality that goes from livestock to the agriculture sector.

4. Discussion

The maximum value in terms of the average temperature variation is 1.33 °C in Ecuador, which means that the country during the analyzed period complies with one of the objectives set out in the Paris Agreement, but that nevertheless should be a matter of concern, as these levels are on the rise, and therefore, it is unavoidable to limit the temperature variation to 1.5 °C. Deforestation has always been seen as a cause of rising temperatures; however, in the case of Ecuador, the opposite happens. According to the results obtained, deforestation as such is not the cause of climatic variations; however, deforestation indirectly causes changes in the short and long term in climate change, that is because when trees are cut, they expel the CO_2 that they have absorbed during their life, which immediately generates changes in the climate, and on the other hand, as its lifespan is up to 150 years because these are still present in the atmosphere over time, so the temperature is affected in the long term. Regarding the short- and long-term relationships with the rest of the variables, it is very important to keep in mind that climate variations are mainly influenced by the presence of greenhouse gases, which come mostly from human activities, and not only naturally within pre-industrial times. In this sense, livestock, and agriculture are activities that emit polluting gases such as CH_4, N_2O, and CO_2, which are responsible for retaining the heat radiated by the sun; therefore, the excessive accumulation of these gases in the atmosphere has forced climate change to happen in a short period of time and throughout history.

Individually, agriculture is the cause of variations in Ecuadorian deforestation, so its effect is quite noticeable in the felling of trees. Likewise, the contribution of livestock and climate change is added, which together imply a strong impact on deforestation. It is clear that there are deforestation problems in Ecuador and the agriculture sector is the main contributor to aggravating this problem, implying a greater demand for arable land. In this sense, the possible policies that the government in conjunction with international organizations and civil society should be aimed at promoting economic activities in a responsible and environmentally friendly manner.

This research takes empirical evidence as a reference, specifically the study by Panday et al. [7]. The interest in relating these two variables: climate change and deforestation. It is mainly due to the fact that when trees are cut down, they emit large amounts of CO_2, which is one of the greenhouse gases that contribute the greatest amount to climate change because these gases are responsible for absorbing the sun's infrared radiation, increasing and retaining heat in the atmosphere. It is important to consider other factors that are affecting climate change. In this context, this section is divided into four groups, taking into consideration the studies that relate climate change to deforestation: deforestation, livestock, CO_2 emissions, and the use of pesticides.

In the first group, there are the studies that relate climate change to deforestation, such as Silva et al. [9], who performed a variable correlation analysis and 2030 prediction using the Land Change Modeler and Earth Trend Modeler interfaces, from whose study they determined that the jungle has control over the climate, and the lack of actions to control the removal of natural vegetation increases deforestation, causing large changes in temperature and rainfall variations over time. For their part, Panday et al. [7] use a combination of long-term rainfall and discharge observations, satellite estimates of evapotranspiration and surface water storage, and numerical model estimates to find that deforestation can substantially alter climate variability and lead to future climate projections that are warmer and more likely to experience drought and fire. According to CIIFEN [27], deforestation leads to an increase in CO_2 in the air, which is one of the main greenhouse gases, so cutting down trees will compound the danger of climate change in the future.

In the second group, there are studies that relate climate change to livestock. On the one hand, González et al. [19] conducted a comprehensive review of a large number of studies on issues related to the human dietary intake of meat concluding that beef is an important source of protein but it also contributes to global warming and climate change. Likewise, Swann et al. [20] use a coupled ecosystem regional atmospheric model (EDBRAMS), and investigated the expected impacts of predicted future land use on the climate of South America, where they found that the transition from natural forest to grassland and agricultural crops will create warmer and drier atmospheric conditions in some countries of the world.

In the third group, the studies that relate the agriculture sector to climate change stand out. Wheeler et al. [21] analyze repeated surveys with the same 275 farmers over a period of five years for the estimation of a binary probit model, and they maintain that agricultural production based on the excessive use of pesticides is affected by positively increasing the perceptions of the risk implied by climate change [28]. Likewise, Mihiretu et al. [22] use quantitative and qualitative data; they analyzed this data using descriptive statistics, linear regression, anomaly index, the Likert rating scale, and conceptual narratives. Therefore, they mention that farmers perceived an increase in temperature and a decrease in rainfall throughout the decades of study, whose anomalies were associated with excessive exploitation of natural resources, and poor management of land and water use, which generated a decrease in crop yields and livestock. Likewise, Demeneix [29] indicates that the effects of intensive agriculture, based on the use of pesticides and fertilizers, are linked to climate change as their use increases nitrate levels, generating serious consequences for wildlife and the climate.

Finally, in the fourth group, space is determined to detail the studies that contrast the results in terms of causality. Foguesatto et al. [26] through principal components analysis and cluster analysis for a sample of Brazilian farmers found that the adoption of sustainable agricultural practices has the ability to mitigate the effects of climate change while minimizing the degradation of natural resources and increasing food production. On the one hand, Greenpeace [30] believes that the main promoter of land-use change is the livestock sector as large tracts of land are used for pasture or the cultivation of animal feed. Likewise, Alves de Oliveira et al. [31] indicate that deforestation is linked to the increased demand for meat and the extension of land due to bad livestock practices. Likewise, Saha et al. [32] use 12 indicators of deforestation to delineate the probability of deforestation, whose results show that the increase in agricultural land and industry leads to the loss of forest area, especially in densely populated nations, and furthermore, that the forested land is under a probable zone of deforestation.

For their part, Flores et al. [33] indicate that when forest ecosystems are attacked by pests and diseases, the use of insecticides or pesticides are necessary to control the destruction of trees, which in turn causes degradation and loss of soil nutrients in forested areas. Instead, Kong et al. [34] use a time series of Landsat data from 1976 to 2016; we identified the key drivers of deforestation using demographic data and qualitative information from local actors and other stakeholders, where they indicate that prolonged and excessive use of chemicals on crops causes soil degradation, converting them into soils unsuitable for food production and in turn generating greater demand for land that leads to deforestation. On the contrary, Abman et al. [35] determine that agricultural productivity, through the use of chemicals and improved seeds, increases crop yields and, at the same time, reduces the pressure to expand agriculture and, therefore, deforestation. Similarly, Pelletier et al. [36] mention that without the use of modern agricultural inputs, the predicted forest cover loss would be approximately double.

Thus, deforestation has always been seen as a cause of rising temperatures, as well as the ownership of forests contributes to reducing global warming because they are responsible for absorbing existing CO_2 in the environment [23]. According to Martins [37], at high latitudes, deforestation can cool or lower the temperature, which does not happen at low latitudes, although this should not be viewed favorably for felling trees at high latitudes. It should be considered that the country is crossed by the equatorial line, which divides the planet into the northern hemisphere and the southern hemisphere; the provinces Esmeraldas, Zamora Chinchipe, Morona Santiago, Orellana, Sucumbíos, and Manabí are where there is higher deforestation. According to González et al. [38], daytime and night-time temperatures present significant differences, with higher temperatures prevailing in the territories that are deforested compared to those covered by trees. Likewise, Bertrand et al. [39] find that there is a greater temperature gap between the climate and the forests located in the lowlands and those in the highlands; thus, the temperature is higher in lower areas, where the speed of climate change is expected to be much higher than in highland areas.

The foregoing implies that to deal with climate change, the country must reduce CO_2 emissions, which come from different economic activities carried out in the country: livestock, agriculture, deforestation, and the burning of fossil fuels that are emitters important CO_2. On the other hand, deforestation problems in Ecuador are accentuated by the participation of the livestock sector, agriculture, and climate change, factors that intervene both in the decrease and in the degradation of forests. It is well known that climate change is closely related to CO_2 emissions, which, being a gas that is responsible for absorbing the heat radiated by the sun on the planet, causes temperature rises, worsening the situation of climate change. Likewise, the use of pesticides implies gas emissions, in this case in a higher proportion of N_2O, which leads to establishing that it has the same behavior as CO_2. It is very important to be clear about the origin of climate change in our country so that in this way, they seek to implement the pertinent measures to counteract accelerated climate change as much as possible.

5. Conclusions

Even though the country maintains the temperature variation below the values established as a global objective and that deforestation does not directly affect climate change, the problem should not be neglected. Although it is true that the country has taken important steps regarding the problem of climate change. However, much remains to be done as governments and society do not give the problem the relevance it deserves, nor are they aware of the serious economic, social, and environmental repercussions that climate change brings. For this, it is very important first to make the population aware that the excessive exploitation of natural resources could lead to the destruction of nature and, therefore, human life. Likewise, intensive reforestation is recommended, not only in wooded areas but also in those areas where deforestation activities are not carried out, such as interprovincial highways and avenues within cities. Reforestation should be a joint effort by public institutions, universities, schools, and society, in general, so that trees become natural greenhouse gas sinks. Additionally, it is important to promote the construction of green buildings in the country through the intervention of the institutions that provide pertinent construction permits, where the coupling of green areas in said buildings is established as a condition to obtain the necessary permits to build.

With the intention of reducing the emission of polluting gases such as CO_2 and N_2O from agricultural activities, it is necessary for the government to invest in education as it is one of the most important aspects when it comes to creating true environmental awareness. Therefore, it is recommended to incorporate into the study plans, topics related to the various problems that the different economic activities carried out by human beings bring with them, and these do so in an environmentally friendly way and try to generate the least amount of greenhouse emissions. In addition to this, the participation of the state is important in terms of supporting companies that have the initiative to manufacture organic fertilizers through the granting of credits and training for the emergence of these ideas and, at the same time, subsidizing the use of organic fertilizers for farmers. In the short term, tax should be applied to companies and industries that emit the largest amount of carbon emissions to reduce the amount of polluting gases in the environment as much as possible. For taxes on polluting gases to be politically viable and economically efficient, the government must direct these revenues in the form of incentives through technological and economic support to those companies that seek to generate less polluting gases and to those that implement both natural and artificial sinks in their place of production. In addition, environmental criteria must be incorporated into existing taxes, which would imply modifying tax rates such as VAT (Value Added Tax) or ICE (Special Consumption Tax), to motivate the consumption of less expensive goods and services pollutants at affordable prices.

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