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A Case Study of Relationship between CO2 Emissions, Growth, Energy and Electricity Consumptions in Morocco

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Abstract

Given the uncontrolled increase in environmental pollution and degradation of environmental quality worldwide, the environmental impact of economic growth has become a major focus in recent decades the most important question is: How does economic growth effect environmental quality? This study addressed this issue, examining the nature of the long-run relationship between economic growth per capita and pollutant emissions in Morocco. For this reason, the ARDL (Autoregressive Distributed Lag) modeling approach was used from 1990 to 2020. This approach mainly includes time series analysis and cointegration. The relationship tested introduces four variables: carbon dioxide (CO2), energy consumption per capita, electricity consumption per capita and GDP per capita. The main results indicate a long-term relationship between economic growth, energy consumption and CO2 emissions, indicating that a 1% increase in electricity consumption increases CO2 emissions by 0.36%. On the other hand, a 1% increase in GDP per capita increases CO2 emissions by 0.76%, and a 1% increase in energy consumption increases emissions by 2.06%. Thus, all variables show a significant effect.

In conclusion, the strategy that Morocco needs to follow to solve our problems is to prioritize investment in research, development and artificial intelligence, while providing adequate training in energy-related fields.

Keywords: Greenhouse Gas Emissions; Energy consumption; Electricity consumption; Environmental quality; Economic growth; ARDL model; Cointegration

1. Introduction

Since the end of the last century, the impact of economic growth on the environment has been crucial, especially in developing countries. This observation has prompted most countries and international organizations to integrate environmental degradation issues into their plans and address them in the context of economic and social development. Morocco has also shown great interest. In its development strategy 2036, it adopts a sustainable development strategy, which promotes a balance between environmental, social and economic dimensions, aiming to improve the quality of life of citizens, strengthen the sustainable management of natural resources, social justice and economic growth meaning promoting environmentally friendly economic activity and social development.

The quality of the environment also has an impact on human and social health. The damage caused by environmental degradation can be diverse and serious. Take, for example, air pollution, which has a direct impact on respiratory health, and can lead to illnesses such as asthma, chronic bronchitis and cardiovascular disease. Environmental degradation also leads to the loss of biodiversity, which can have social and health consequences, by reducing access to natural areas and diminishing the diversity of animal and plant species. In short, environmental quality has a profound impact on health and society, with both immediate and long-term consequences. Protecting the environment and reducing pollution is essential to preserving human health and improving the quality of life of society as a whole.

In this context, concerns about global warming and greenhouse gases (GHGs) have prompted most countries to initiate a process with the ultimate of controlling these emissions. Their most important target is to reduce the impact of these emissions on global warming. This process led to Morocco organizing COP22 in 2016.

Improving energy efficiency is one of the best ways to reduce GHG emissions while minimizing the negative impact on living standards. Therefore, the purpose of this study is to analyze the relationship between economic growth and environmental quality. For that, it highlights in this relationship some variables such as GDP, energy factor (energy consumption and electricity consumption) and carbon dioxide emissions. To this end, this paper proposes an empirical approach to examine the relationship between carbon dioxide emissions, economic growth, energy consumption and electricity consumption during the period 1990-2020.

This paper is structured as follows. The second section introduces the theoretical background. The third second shows the energy consumption status of Morocco in the past two decades. The third section uses the ARDL cointegration methodology to analyze the long-term relationship between carbon dioxide emissions and economic growth. Finally, the fourth section provides concluding remarks.

2. Theoretical background

To examine the sources of emissions, **Ehrlich and Holdren** (1971) tried to break down the impact of the total economy on the environment into several factors, showing the existence of a relationship between the environment and economic activities defined by the following equation, known as the IPAT equation:

$$I = P * A * T \qquad \textbf{(Eq. 1)}$$

Where: variable **I** indicates the environmental impact; variable **P** represents the population of an area; variable **A** represents the income per capita; variable T symbolizes the technology or environmental effect per unit of production.

Commoner et al. (1971) expressed this IPAT equation as follows:

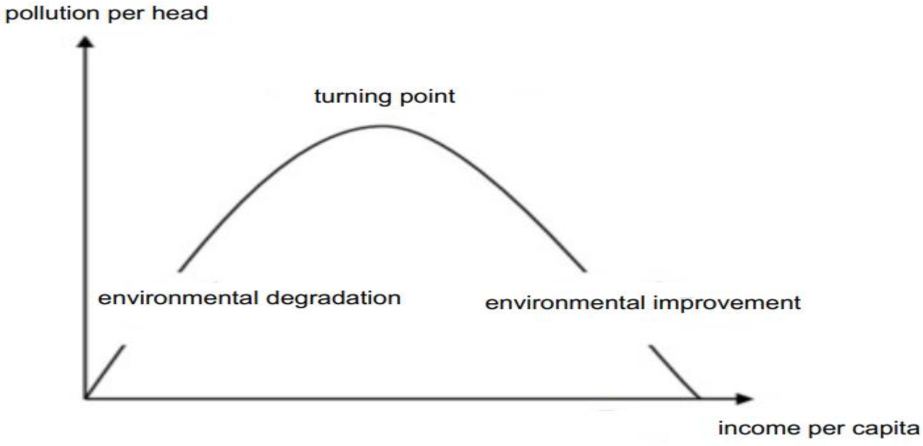
$$E = (P) \times (A/P) \times (E/A) \qquad \textbf{(Eq. 2)}$$

Where: E is the level of pollutant emissions expressed in terms of population size (P); (A/P) represents income per capita, and (E /A) indicates pollution intensity of the economy.

According to equation 1, an increase in the income per capita *(A /P) leads to* an improvement in environmental quality, but if, for example, an increase in the income per capita is associated with a significant reduction in the intensity of economic pollution (E/A), then equation *2* remains too general and does not allow us to understand how such reductions can be possible, since it ignores different possible interactions between all these components.

When examining the interactions between population, wealth, and technology, the IPAT equation offers several interpretations. The relationship and interdependence between factors P, A, and T play a decisive role in understanding the impact of these variables on environmental quality. Two major scenarios can be presented here: ***(1)*** if one of the factors increases and others remain constant, a new environmental burden; ***(2)*** if the three factors are interdependent, the result can be rather difficult to interpret. However, **Simon Kuznets** (1955) demonstrated a correlation between two variables: measured environmental quality and income per capita, known as the Environmental Kuznets Curve (EKC) (***Figure*** 1).

Figure 1. Presentation of the Environmental Kuznets Curve (EKC)



Source: World Trade Organization, WTO (1999)

The EKC is based on the hypothesis that industrialization and the intensive exploitation of natural resources as well as the use of non-clean production technologies accelerate the release of environmentally harmful emissions and subsequently increase the pressure on the environmental quality. However, growth hurts the environment even in the early stages of development; above a certain threshold of income per capita, growth then leads to an improvement in environmental quality. The relationship between income per capita and environmental degradation would therefore take the form of an inverted U.

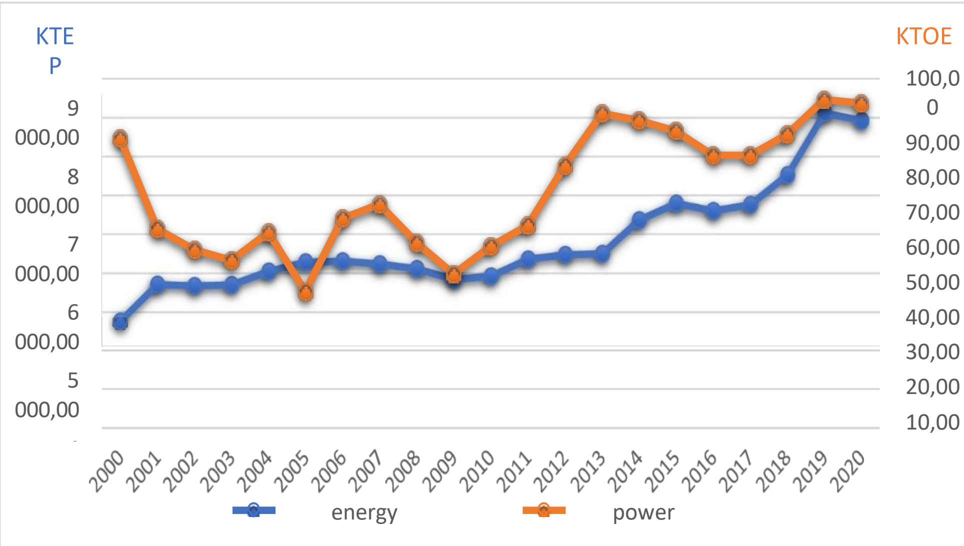
Since the early 1990s, EKC has become a central topic in numerous empirical studies. This inverted U-shaped curve was described by Grossman and Krueger (1991) on the environmental impacts of the North American Free Trade Agreement (NAFTA) and later by Shafik and Bandyopadhyay (1992) in their World Development Report.

The World Bank Report (1992) and the results of a survey conducted by Panayotou (1993) for the International Labour Organization show that there is an inverted U or EKC relationship between some pollution indicators (related to flow or resources) and income per capita. In contrast, El Alaoui and Nekrach (2018) concluded that the EKC is vague and uncertain when they attempted to examine the relationship between economic growth and environmental quality in four countries: Morocco, Algeria, Tunisia, and Egypt, by first testing the basic EKC for each country over the period 1970-2010, and in the second stage introducing into the basic EKC equation certain variables such as the economic openness indicator, the school enrolment rate, and the urbanization rate. They found that the relationship between economic growth and the environment is complex and ambiguous since it is impossible to find a single form of this relationship, and any variable introduced into the basic model can provide an explanation for the relationship between growth and environmental quality.

3. Morocco's Energy Balance Shows a Growing Deficit

In Morocco, demographic and economic growth have led to a significant increase in energy consumption over the last two decades. Thus, the combination of the decline in hydrocarbon production and rapidly rising demand for energy products resulting from economic growth, population growth, and social development is the main cause of this energy balance deficit (Figure 2).

Figure 2. Domestic demand and energy production trends over the period 1990-2020, in KTOE



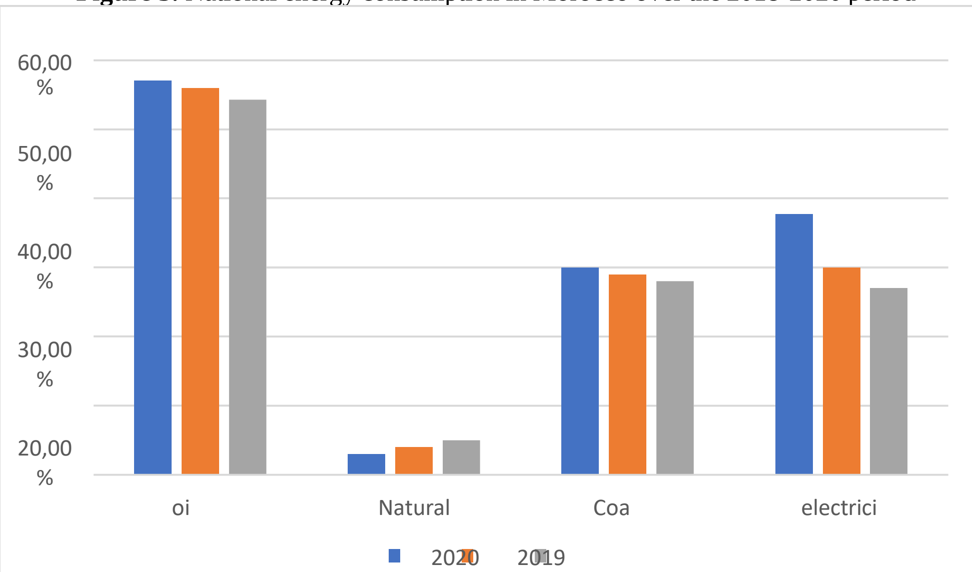
Source: Based on data from the Moroccan Energy Observatory, 2023.
Note: KTOE is the Kiloton of oil equivalent unit.

The figure above shows that energy consumption amplified by 97% between 2000 and 2020, from 2763 ktoe (kilotons of oil equivalent) in 2000 to 7926 ktoe in 2020. Furthermore, consumption data by type of product shows that oil consumption accounts for a significant part (69%), followed by electricity (16%), coal (nearly 11%), anthracite (3%) and natural gas (1%). While domestic energy production (anthracite, naturalgas, and crude oil) remains stable and has not increased significantly, averaging 162 ktoe between 2000 and 2020.

The contribution of economic growth from the energy sector shows a downward trend. Annual energy consumption per capita was 0.56 tonnes of oil equivalent (Toe) in 2015, well below the world average of 1.50 Toe. It is characterized by the predominance of coal, petroleum coke and electricity as primary raw resources. Moreover, the overall structure of final energy consumption can be analyzed using energy intensity, which is defined as a measure of the energy efficiency of the economy which is calculated as the ratio of energy consumption to gross domestic product. This ratio is generally expressed in Toe per million Moroccan dirhams of GDP.

Analysis of data between 1991 and 2015 shows that the highest energy intensity in Morocco was 3.74 mj/USD (megajoules/dollar) in 2005 (Data World Bank, 2021), and the lowest was 3.15 mj/USD in 2015. The overall trend of this intensity remains relatively stable. The share of industry share in final energy consumption is currently estimated at 22%, and the reduction in national energy consumption in this sector will be 17% by 2030. Fuels and petroleum products account for almost 70% of final energy consumption in industrial, including 1% in mining and quarrying, 12.47% in the agri-food sector, 31.62% in chemicals and 25.96% in metallurgy and metal products. Thus, the agri-food sector is the second-largest energy consumer after the building materials sector. Other important energy-consuming sectors with significant energy-saving potential for national industrial competitiveness are textiles (especially electricity), mining and transport (especially oil).

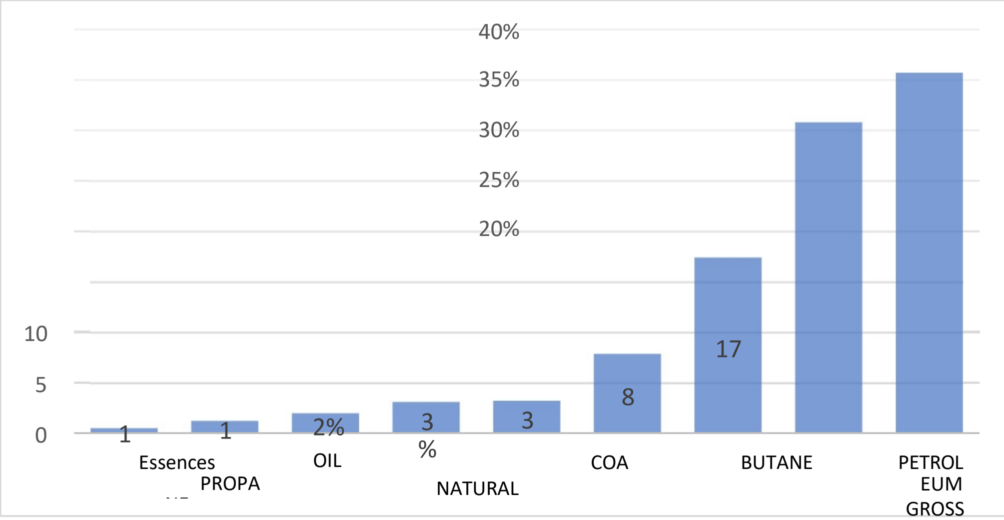
Figure 3. National energy consumption in Morocco over the 2018-2020 period



Source: Based on data from the Moroccan Energy Observatory, 2023

On the other hand, Morocco is a country deeply dependent on energy imports, especially fossil fuels, which exposes its development to the risk of oil price volatility and significantly weighs on its energy bill. The following figure displays that energy imports consisted mainly of crude oil (36%), diesel (31%), butane (17%) and electricity (3%) in 2020.

Figure 4. Share of imports by energy products between 1990 and 2020 (millions MAD)

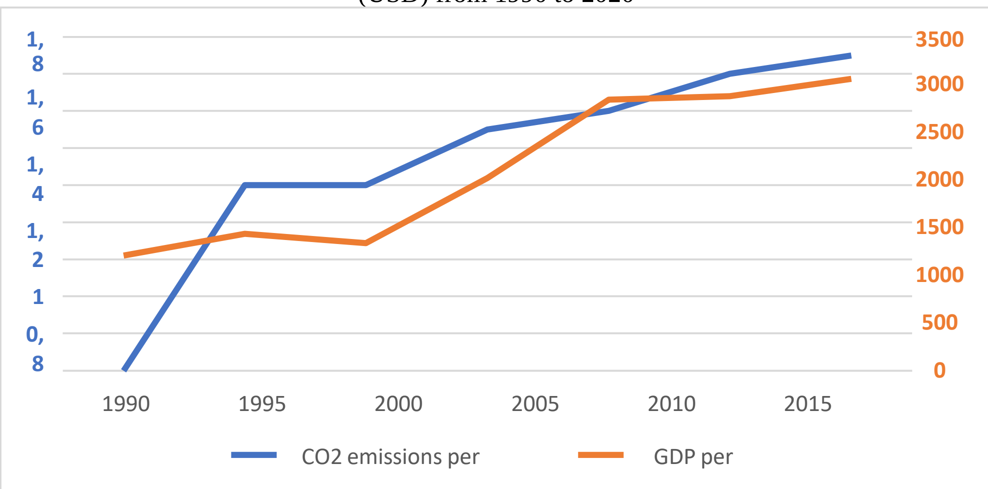


Source: Based on data from the Moroccan Energy Observatory, 2023

4. Carbon dioxide emissions in Morocco (CO2)

In Morocco, the flow of carbon dioxide emissions (CO2) indicate an upward trend, suggesting that it refer to a global significant improvement in the population's standard of living since GDP per capita has augmented sharply over the period between 1990 and 2020 (**Figure** 4). For that, the variability of the air pollution indicator (CO2) used is similar to GDP per capita, whose rapid economic growth is accompanied by an approximately equal rapid deterioration in environmental quality.

Figure 5. Trends in CO2 emissions per capita (metric tonnes per capita) and GDP per capita (USD) from 1990 to 2020

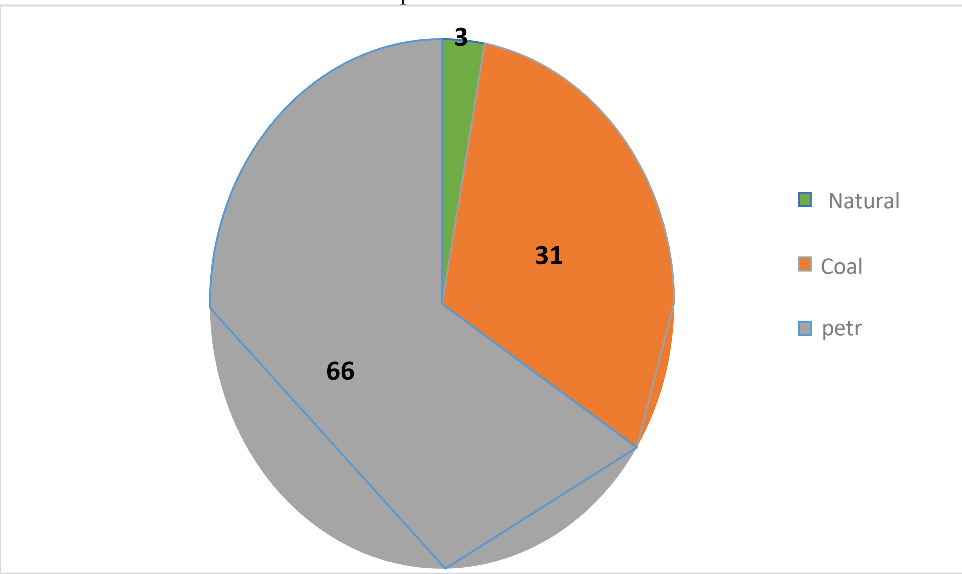


Source: Based on data from WDI, World Bank 2023

Therefore, the data analysis of the EKC hypothesis reveals an everincreasing trend. This seems logical as Moroccan demographics have undergone a deep transition since 1980. According to the World Bank, Morocco's population growth rate has slowed: 2.39% in 1980; 1.83% in 1990; 1.18% in 2000; 1.28% in 2010 and 1.18% in 2020 (WDI, World Bank, 2021). Interestingly, CO2 emissions per capita are tending upward, placing Morocco 136th out of 184 countries in the world for CO2 emissions, ranging from least pollutants although it is not an industrialized country. This highlights a downtrend in domestic air quality over the period 1990-2020. These concluding remarks are supported by the International Energy Agency data, which also highlights other interesting points:

- The main source of CO2 emissions is oil consumption (66%) followed by coal (31%) and natural gas (3%) (**Figure** 5).

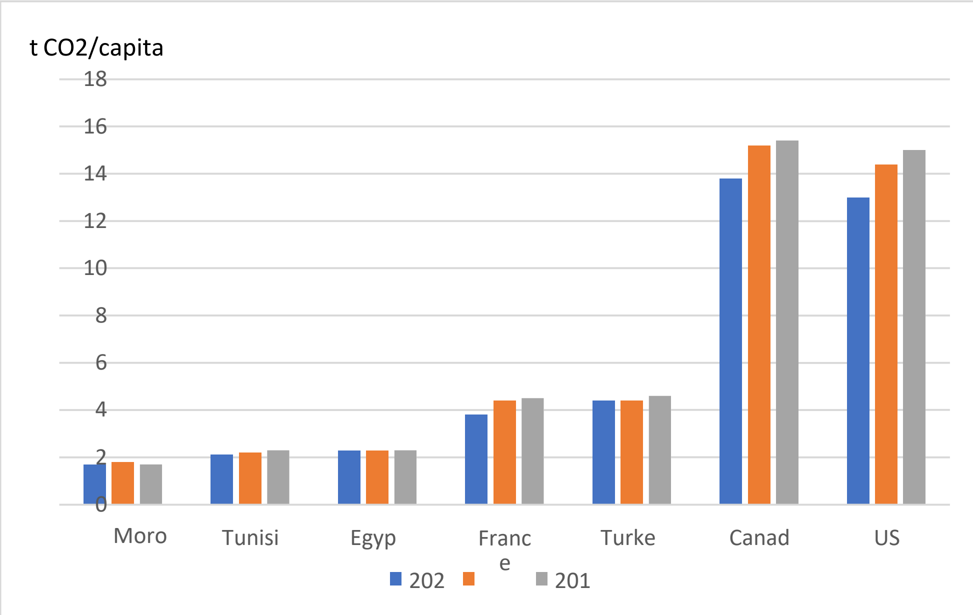
Figure 6. Average share of CO2 emissions by an energy source for Morocco, in %, the period 1990-2020



Source: Elaborated according to International Energy Agency data, 2021

- CO2 emissions recorded an upward trend during the period 1990-2020, indicating that Morocco is a low emitter (**Figure** 6).

Figure 7. CO2 emissions per capita (tonne CO2 per capita) in Morocco and other countries, 2020

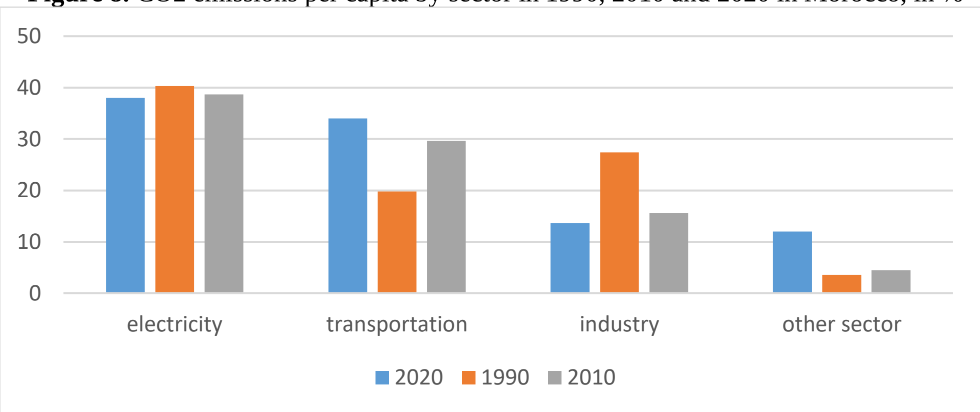


Source: Elaborated according to International Energy Agency Data, 2023

Compared to some countries in the Mediterranean region, Morocco's emissions are significantly lower than those of Tunisia, Egypt and France, as well as countries such as Turkey, Canada and the United States. Nevertheless, some developed countries have succeeded in reducing their CO2 emissions per capita in recent years, while Morocco's emissions, though low by comparison, are rising fairly moderately.

Generally speaking, the electricity and transport sectors are the most polluting during the period 1990-2020, followed by the manufacturing and public sectors (Figure 7).

Figure 8. CO2 emissions per capita by sector in 1990, 2010 and 2020 in Morocco, in %



Source: Ministry of Energy and Mines, 2023

5. Methodological approach and analysis of model results

According to the above analysis, environmental degradation in Morocco is linked to three major variables: income per capita, energy consumption per capita and electricity consumption per capita. For this reason, it will be useful to test the existence of the long-term relationship between these variables, where environmental degradation will be measured by carbon dioxide emissions (CO2 emissions) because of the availability of data. Applying the econometric approach related to time series analysis and cointegration, this paper tries to check this relationship according to the following hypotheses:

(i) There is a ***unidirectional*** relationship between, on the one hand, each of the explanatory variables and, on the other hand, environmental degradation*;*

(ii) ***T***here is a ***bidirectional*** relationship (feedback effect) between, on the one hand, each of the explanatory variables and, on the other hand, environmental degradation; or

(iii) There is ***no relationship*** between the explanatory variables, and between the environmental degradation variable and the explanatory variables.

According to the EKC hypothesis, the long-term relationship between economic growth and environmental degradation can be modeled in the following linear logarithmic form:

$$\mathbf{LnCO2t = \beta 0 + \beta 1\ LnCe_t + \beta 2 Ln\_GDPt + \beta 3\ Lncelt + S_t} \qquad \textbf{Eq. 3}$$

Where: ***Ln_co2t*** is CO2 emissions per capita; ***LnCet*** is energy consumption per capita; ***LnGDPt*** is real GDP per capita; ***LnCelt*** is energy consumption per capita of electricity per capita; s_t : error term, and ***β0*** : long-term elasticity.of CO2 emissions

The model presented above (**Eq. 3**) will be tested from 1990 to 2020, i.e. 31 observations. The table below shows the descriptive statistics of the variables.

Table 1. Descriptive statistics of the data used

	Description	Deviation Type	Medium	Min	Max	Units	Source
GDP	GDP per capita	785,44	2169,99	1206,01	3058,69	US$/person	World Bank
CO2	Carbon emissions per capita	0,31	1,25	0,82	1,84	TM/person	World Bank
Cet[1]	Energy consumption	0,10	0,45	0,32	0,61	PET/person	International

[1] is the total consumption of: Anthracite, Petroleum Coke, Natural Gas and Coal

	n percapita						Energy Agency
Celt	Consumption of electricity per capita	0,29	0,05	0,03	0,08	PET/person	Agency International Energy

Source: Authors

To test our model, the following structured methodological approach is applied:

- Testing the stationarity of the time series;
- Select the optimum number of delays;
- Perform the "Bound Test" to establish the long-term relationship;
- Estimating long-term and short-term coefficients;
- Test model stability using residual analysis and the CUSUM and CUSUMSQtechnique (Brown et al., 1975).

According to the Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) stationarity tests, the variables do not have the same level of stationarity, since the variables ln_co2, ln_GDP and ln_Ce are stationary in the first difference, while the variable ln_Cel is stationary at levels (**Table 2**). These results show therefore that the stationarity of the time series has different levels of stationarity, either 0 or 1; indicating that it will be compatible to adopt the ARDL model.

Table 2. The stationarity tests for the time series

Variables	Level		In first difference	
	ADF	**Results**	**ADF**	**Results**
Augmented Dickey-Fuller (ADF)				
Ln_CO2	-1,05 (Prob :0.91)	Non-stationary	-4,19 (Prob 0.01)	**Stationary**
Ln_GDP	-3,21 (Prob 0.10)	Non-stationary	-4,17 (Prob 0.01)	**Stationary**
Ln_Ce	-1,58 (Prob 0.77)	Non-stationary	-3,66 (Prob 0.04)	**Stationary**
Ln_Cel	1,93 (Prob 0.03)	Stationary	----	----
Phillips Perron (PP)				
Ln_CO2	-1,02 (Prob: 0.92)	Non-stationary	-5,17 (Prob :0.00)	**Stationary**
Ln_GDP	-1,67 (Prob: 0.73)	Non-stationary	-4,19 (Prob : 0.01)	**Stationary**
Ln_ce	-1,61 (Prob: 0.76)	Non-stationary	-5,38 (Prob: 0.00)	**Stationary**
Ln_cel	1,94 (Prob 0.04)	Stationary	----	----

Source: Authors, Eviews.9 software

Before applying the ARDL model, it is necessary to determine the optimal number ofdelays (Table 3).

Table 3. Selection of optimal model delay

Lag	LogL(a)	LR(b)	FPE(c)	AIC(d)	SC(e)	HQ(d)
0	-71.4671	NA	0.0063	6.2889	6.4853	6.3410
1	-0.6698(a)	112.0958(a)	6.74e-05(a)	1.7225(a)	2.7042(a)	1.9829(a)
2	6.0665	8.4204	0.0002	2.4944	4.2615	2.9633
3	29.8921	21.8401	0.0001	1.8423	4.3948	2.5195

Note: *(a)* Indicates lag order selected by the criterion (Log-likelihood value); *(b)* R: sequential modified LR test statistic (each test at 5% level); *(c)* FPE: Final prediction error; ***(d)*** AIC: Akaike information criterion; (e) SC: Schwarz information criterion, and (f) * HQ: Hannan-Quinn information criterion.

The results indicate that the optimal lag is p=1, meaning that the ARDL approach can be used to determine the long-term relationship between environmental quality and the explanatory variables. To do this, the "Bound Test" is applied, calculating the F-statistic (**Table** 4).

Table 4. ARDL results, Bound Test

Test Statistic	**Value**	**K**
F-statistic	4.0356	3
Critical Value Bounds		
Significance	**I0 Bound(a)**	**I1 Bound(b)**
10%	2.72	3.77
5%	3.23	4.00
2.5%	3.69	4.01

Source: Authors, Eviews.9 software

Note: (a) Fisher's critical upper bound value for level 0; (b) Fisher's critical upper bound value for level 1.

According to table 4, the results of the cointegration test at the bounds indicate that theFisher statistic (4.03) is greater than the upper bound Fisher critical value for all levels of significance, confirming the cointegration of the time series and, therefore, the existence of a short- and/or long-term relationship between the explanatory variables and the dependent variable. But, before that, we must check the causality using the Granger causality test (**Table** 5).

Table 5. Granger causality test

Null Hypothesis	**Obs**	**F-Statistic**	**Prob.**	**causal result**
LN_ELECT does not Granger Cause LN_CO2	26	3.37760	0.0535	Unidirectional
LN_CO2 does not Granger Cause LN_ELECT		0.82873	0.4504	Bidirectional
LN_GDP does not Granger Cause LN_CO2	26	6.39945	0.0357	Unidirectional
LN_CO2 does not Granger Cause LN_GDP		3.62897	0.0443	Unidirectional

LN_CENER does not Granger Cause LN_CO2	26	5.18783	0.0148	Unidirectional
LN_CO2 does not Granger Cause LN_CENER		0.19821	0.8217	Bidirectional
LN_GDP does not Granger Cause LN_ELECT	29	0.12827	0.8802	Bidirectional
LN_ELECT does not Granger Cause LN_GDP		4.84280	0.0171	Unidirectional
LN_CENER does not Granger Cause LN_ELECT	29	0.61793	0.5474	Bidirectional
LN_ELECT does not Granger Cause LN_CENER		0.22031	0.8039	Bidirectional
LN_CENER does not Granger Cause LN_GDP	29	7.22959	0.0035	Unidirectional
LN_GDP does not Granger Cause LN_CENER		0.01359	0.9865	Bidirectional

Source: Authors, Eviews.9 software

Table 5 shows that the Granger causality test is accepted for the following unidirectional relationships: ***(i)*** electricity consumption causes CO2 emissions and GDP; ***(ii)*** LN_CO2 causes LN_GDP; ***(iii)*** GDP causes CO2 emissions, and ***(iv)*** Energy consumption causes CO2 and GDP. And there are bidirectional relationships for ***(i)*** LN_CO2 does not cause electricity consumption;***(ii)*** LN_CO2 does not cause energy consumption; ***(iii)*** GDP does not cause electricity consumption; ***(iv)*** energy consumption does not cause electricity consumption and vice versa; and ***(v)*** LN_GDP does not cause energy consumption. Overall, there is a causal relationship between the two main variables of interest, and this relationship goes in the direction of economic growth towards CO2 emissions.

The model's long-term estimate (Eq. 3) shows that energy consumption, electricity consumption and GDP have a positive effect on CO2 emissions.

Ln_co2t =	***0.3508 +***	***0.3637 Ln_cenert+***	***0.7601 Ln_GDPt +***	***2.061 Ln elect***
Std. Error:	0.0987	0.1658	0.0000	0.3267
t-Statistic:	3.5558	2.1938	1.8128	6.3072

These results indicate that a 1% increase in electricity consumption (toe per capita) increases CO2 emissions (metric tons per capita) by 0.36%. On the other hand, a 1% increase in GDP per capita increases CO2 emissions (metric tons per capita) by 0.76%, and a 1% increase in energy consumption increases emissions by 2.06%. Thus, all variables show a significant effect.

As for short-term relationship estimation, the model is written as follows:

$D(Ln\_co2)_t =$	$-0.6198 +$	$0.3534\ Ln\_cenert_t -$	$0.000002 Ln\_GDP_t +$	$1.2773\ Lnelect_t$
Std. Error:	0.1048	0.1108	0.00004	0.2820
t-Statistic:	-5.9131	3.1889	-0.04257	4.5293

The results of estimating the short-term relationship show that the coefficient of the error-correction term is significant and negative (-0.6198), implying that the speed of short-term adjustment to reach equilibrium is significant. Furthermore, this term is equal to -0.6198, meaning that when CO2 emissions per capita are above or below their equilibrium value, they would adjust by 61% per year.

The coefficients of the lagged variables represent short-term elasticity. These are significant with the expected signs for all variables, except GDP. For example,a 1% rise in energy consumption per capita would imply a 0.35% rise in CO2 emissions per capita in the short term.

Diagnostic tests of the ARDL regression were also carried out to validate the model (Table 6).

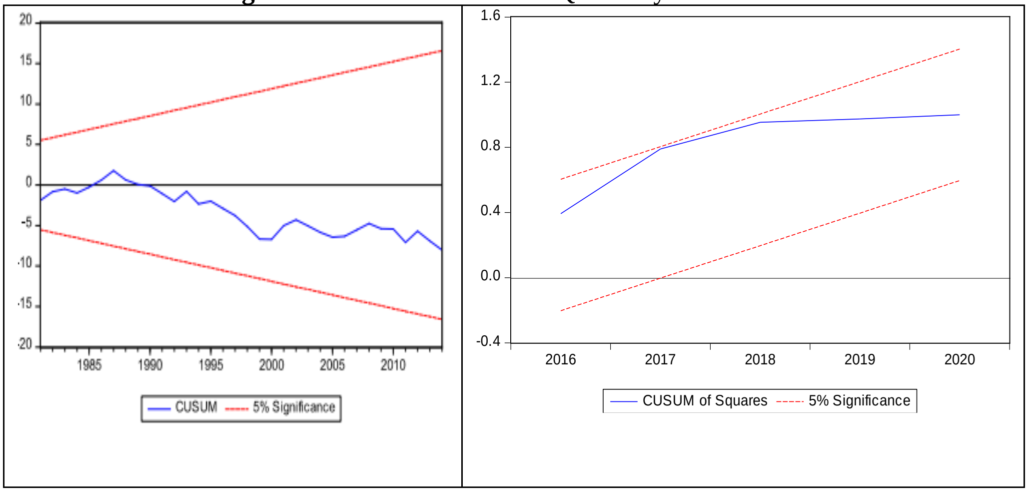
Table 6. Model robustness tests

	Breusch Godfrey Test H: Autocorrelation	**Jarque-Bera Test** H: Normality	**ARCH Test** H: Heteroskedasticity	**Ramsey Rest Test** H: Specification
F-Statistic	0.029	7.480	1.030	1.900
Prob.	0.970	0.200	0.530	0,460

Source: Authors, Eviews.9 software

The results of this table confirm the validation of the estimated model, showing that the probabilities for all four tests are greater than 5%. The null hypothesis (H0) is therefore accepted for each test. It can be concluded that the errors of the ARDL model tested are not autocorrelated, and are normally distributed. The model presented is well specified. The same results are also illustrated by the CUSUM and CISUMQ stability tests, i.e. the model coefficients are stable at the 5% threshold (Figure 9).

Figure 9. CUSUM and CISUMQ stability tests



Source: Developed by the authors

Conclusion

This paper tries to examine the relationship between pollutant emissions, economic growth and energy consumption in Morocco over the period 1990-2020, using the time-series analysis and cointegration test. The results show a long-term relationship between economic growth, energy consumption and CO_2 emissions, indicating that a 1% increase in electricity consumption (toe per capita) increases CO_2 emissions (metric tons per capita) by 0.36%. On the other hand, a 1% increase in GDP per capita increases CO_2 emissions (metric tons per capita) by 0.76%, and a 1% increase in energy consumption increases emissions by 2.06%. Thus, all variables show a significant effect.

However, the most important finding to emerge from this modest study is that a sustainable development strategy must be put in place, based on the transition to a green economy that balances the improvement of environmental quality, economic growth and social development. This strategy can reinforce sustainable management of natural resources and promote environmentally friendly economic activities. This approach will enable Morocco to make a typical leap forward, thereby improving its economic situation, foreign energy independence, environmental quality and social justice.

Finally, Morocco must invest in research and development and artificial intelligence, provide adequate training in energy-related fields, and encourage young people to take up renewable energies and environmental protection. To achieve this goal, Morocco must accelerate its strategy of welfare state and territorial justice to build a social system capable of understanding the challenge that environmental degradation represents for our health and the future of all people in the world regardless of their origin, ethnicity, geographical location, gender and so on. We are all connected, we must believe that our activities have a deep effect on our ecosystem.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All data are included in the content of the paper.

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