Effects of institutional quality, agriculture, and industry on CO_2 emissions in Tunisia: Evidence from an ARDL approach

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Abstract

This paper investigates the impact of institutional quality, the agricultural and industrial sectors, as well as renewable and non-renewable energy consumption on CO_2 emissions in Tunisia, while accounting for institutional challenges and the energy transition. Using the Autoregressive Distributed Lag (ARDL) bounds testing approach for the period 1996-2023, the analysis explores the linear relationships between these variables and CO_2 emissions, incorporating the evolution of the country's economic and energy policies. The results show that, in the long term, non-renewable energy consumption and industrial added value significantly contribute to the increase in CO_2 emissions, whereas institutional quality plays a moderating role by influencing the trajectory of emissions. This suggests that improvements in governance and institutional frameworks could be instrumental in reducing CO_2 emissions. In the short term, non-renewable energy consumption, industrial added value, and agriculture emerge as key drivers of rising emissions, although institutional quality acts as a stabilizer, mitigating fluctuations and facilitating adjustments to past imbalances. This study highlights the complex interactions among institutional, economic, and energy policies and their effects on the environment, emphasizing the importance of strengthening institutions to support a sustainable energy transition.

Keywords: agriculture, ARDL model, CO_2 emissions, institutional quality, nonrenewable energy, renewable energy, sustainable development.

JEL classification: B15, C22, P18, Q01, Q1, Q2, Q28

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1. Introduction

Combating CO_2 emissions constitutes a major global challenge, necessitating robust institutional quality to effectively frame and implement environmental policies. Institutions play a pivotal role in the implementation of sustainable measures. Nonetheless, divergences persist regarding the approaches adopted. Developed countries primarily rely on technological innovation, whereas developing nations favour immediate solutions. sometimes to the detriment of long-term environmental objectives. These issues are further exacerbated by economic inequalities, geopolitical tensions, and resistance to change all of which undermine the effectiveness of climate policies and underscore the need for profound institutional reforms.

In Tunisia, the quality of environmental institutions has undergone significant development since the 1980s. The establishment of the Ministry of the Environment in 1989, the adoption of the Environmental Code in 1991, and the creation of the National Agency for Environmental Protection (ANPE) laid the groundwork for a structured institutional framework. Tunisia's international commitment to environmental issues was further strengthened by its participation in the Rio Earth Summit in 1992, followed by the launch of the National Environmental Action Plan in 1995. More recently, ambitious initiatives such as the National Strategy for Sustainable Development (SNDD 2016-2030) and the National Climate Change Strategy (PNCC) reflect the country's determination to pursue a sustainable development trajectory.

Despite this progress, numerous challenges remain; institutional shortcomings, budgetary constraints, and limited coordination between public and private actors. These limitations hinder the effectiveness of environmental policies, despite the efforts undertaken. In 2023, CO_2 emissions reached 32.79 million tons, compared to 9.50 million in 1980, an average annual growth rate of 2.92%. Per capita emissions also rose to a record level of 2.7 tons, reflecting the expansion of industrialisation, the predominance of fossil fuels, and intensive agricultural practices. This trend is largely driven by the dependence of the industrial and agricultural sectors on non-renewable energy sources, despite efforts towards energy diversification.

At present, Tunisia's environmental priorities include the energy transition, waste management, and climate change adaptation. However, the success of these transitions will depend to a large extent on a significant improvement in environmental governance. It is within this context that the present study is situated. Employing an Autoregressive Distributed Lag (ARDL) model, this research examines the impact of institutional quality, as well as the agricultural, industrial, and energy sectors, on CO_2 emissions in Tunisia. The objective is to provide robust empirical evidence to advise the formulation of targeted and sustainable environmental policies.

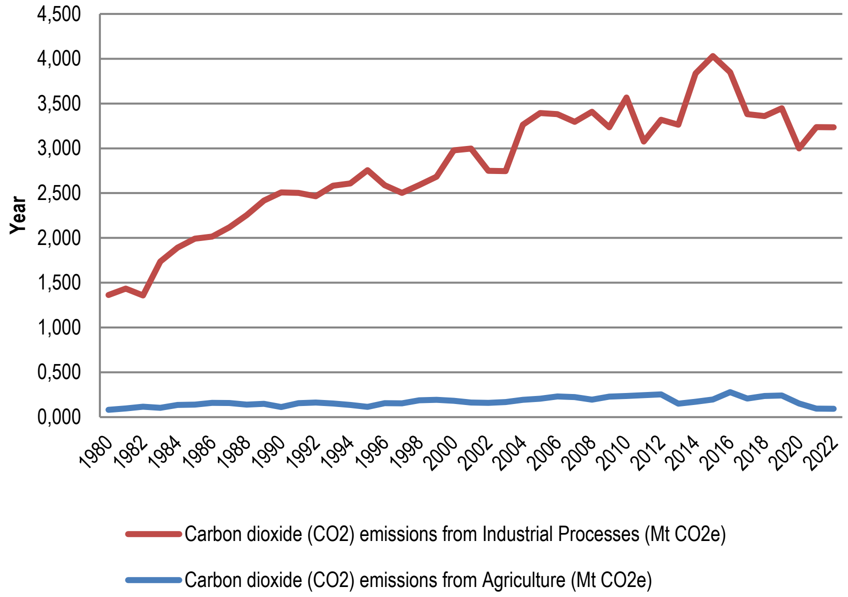
2. Tunisia's environmental challenges: Institutional quality and the agricultural and industrial sectors

A growing debate highlights the key role of institutional quality in the energy transition towards renewable sources and the improvement of environmental quality. This debate particularly handles energy-intensive sectors such as industry and agriculture, which remain largely dependent on fossil fuels. The New Institutional Economics (NIE) emphasises the importance of effective institutions and rigorous governance to ensure the success of reforms and sustainable growth (Chtourou, 2004).

Since the 1980s, Tunisia has made renewable energy a strategic priority, placing it at the core of its energy efficiency policy. The country strengthened its legal and institutional framework with the establishment of the Ministry of the Environment in 1989, the creation of the National Agency for Environmental Protection (ANPE) in 1988, and the adoption of the Environmental Code in 1991. On the international stage, Tunisia committed itself at the 1992 Earth Summit in Rio and launched a National Environmental Action Plan in 1995. More recently, environmental policy has been reinforced by the framework law No. 2020-72 on waste management, the National Climate Change Strategy (PNCC, 2021), and a target of 30% renewable energy in the national energy mix by 2030. Reforestation campaigns were also carried out in 2023.

The agricultural and industrial sectors accounted for 32.98% of Tunisia's GDP in 2023, with agriculture representing 9.47% and industry 23.51%. These sectors present significant environmental challenges, including intensive agricultural practices, high energy consumption, and polluting industrial emissions. According to Figure 1, agricultural CO_2 emissions increased until 2016 before beginning to decline, while industrial emissions rose in parallel with national energy consumption until 2019.

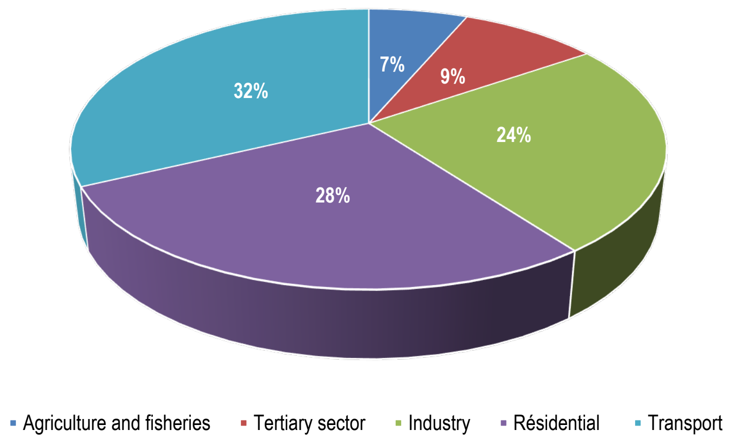
Figure 1 – Evolution of CO_2 emissions in the agricultural and industrial sectors



Source: WDI

In 2023, the combined energy consumption of the agricultural and industrial sectors accounted for 30.8% of the country's final energy demand (see Figure 2).

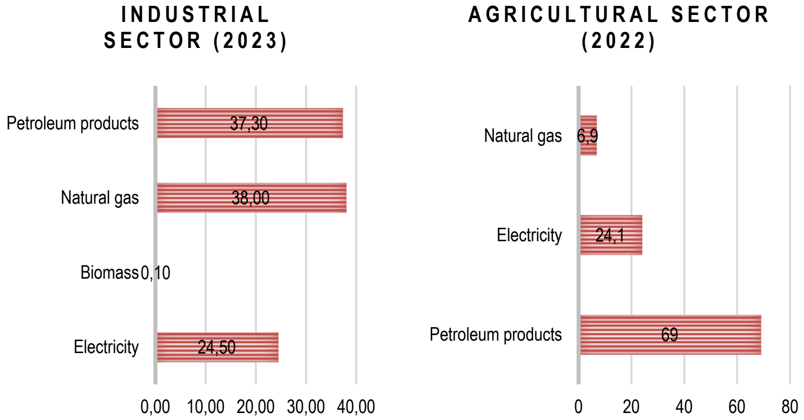
Figure 2 – Structure of final consumption by sector in 2023



Source: ANME[1]

The industrial sector, which is particularly energy-intensive, relies mainly on natural gas (38%), petroleum products (37.3%), and electricity (24%) (Figure 3). Agriculture primarily consumes petroleum products (69%) and electricity (24%), with a growing share of photovoltaic energy used for water pumping.

Figure 3 – Structure of final consumption in agriculture and industry by energy type



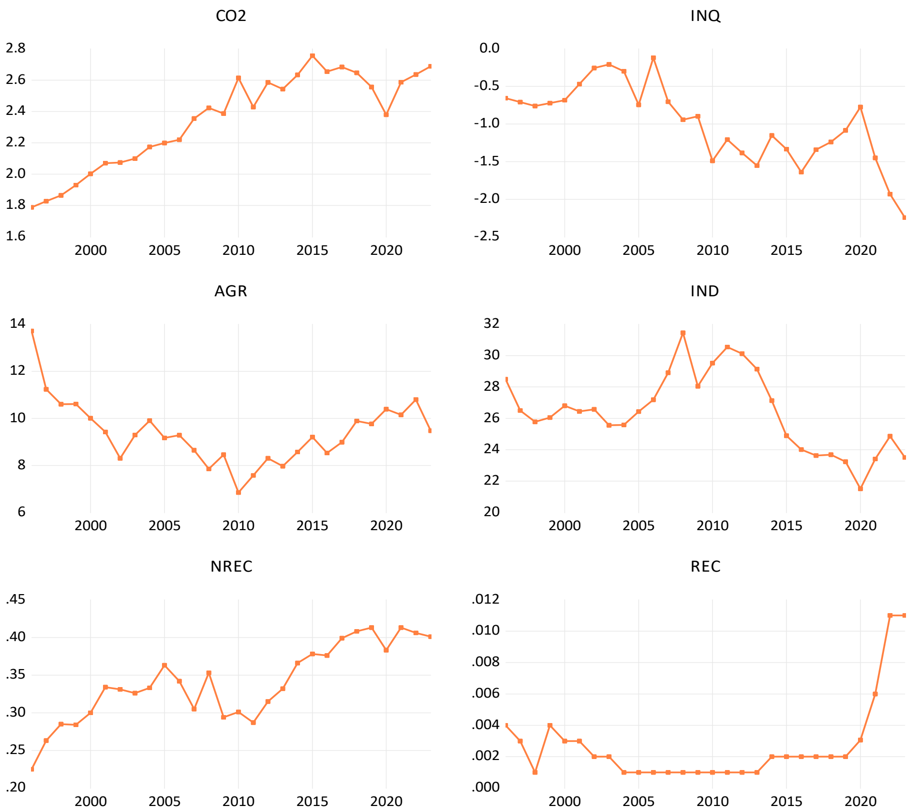
Source: ANME

[1] ANME: The National Agency for Energy Management.

The share of renewable energy remains marginal (0.8% in 2022), reflecting structural constraints in investment and regulation. Figure 4 highlights a decline in institutional quality since 2010, which has hindered the effective implementation of environmental policies. In conclusion, Tunisia must strengthen its governance and improve coordination between public and private players in order to successfully achieve the energy transition, fully integrating the agricultural and industrial sectors into this process.

The Tunisian industrial sector, which accounts for nearly 24% of final energy demand, is one of the country's main energy consumers, particularly in the cement, chemical, metallurgy, and agri-food industries. This sector relies primarily on natural gas (38%), petroleum products (37.3%), and electricity (24%). To address energy and environmental challenges, Tunisia has implemented several policies aimed at modernising industrial processes, improving energy efficiency, and integrating renewable energy sources.

Figure 4 – Evolution of variables from 1996 to 2023



Source: Author's calculation (2025)

However, the decline in institutional quality since 2010 has undermined the effectiveness of these policies. Graphical data reveal a correlation between CO_2 emissions, the energy structure of the industrial sector, and the country's environmental governance.

3. Literature review

The effects of institutional quality, the agricultural and industrial sectors, as well as the energy sector, on CO_2 emissions in Tunisia have been extensively examined through recent studies employing advanced econometric approaches. For instance, Gharbi et al. (2025) apply the ARDL model to the period 1988-2021 and demonstrate that tourism and industrialisation exacerbate CO_2 emissions, while renewable energy and capital formation contribute to their reduction. Comparative studies confirm these dynamics. Amin and Rahman (2024) highlight that industrialisation increases emissions in developing countries, whereas the agricultural sector tends to mitigate them. A similar trend is observed in Vietnam, where Raihan (2023) finds that economic growth and rising energy consumption drive emissions upwards, while agricultural added value helps reduce them.

Other studies stress the role of renewable energy and sustainable agricultural practices in reducing CO_2 emissions, although results vary across national contexts (Chaouali et al., 2023; Waheed et al., 2022). In Tunisia, several studies identify specific policy levers. Talbi et al. (2022) emphasise the importance of energy efficiency in the industrial sector. Similarly, Ben Jebli and Ben Youssef (2019), as well as Farhani (2014), underline the need to promote renewable energy and implement sustainable energy policies. An analysis of Tunisian data over the period 2000-2022 reveals a general increase in CO_2 emissions, with a slight decline after 2010 followed by a recent rebound, correlated with the growing consumption of non-renewable energy. In this context, Saadaoui and Chtourou (2022) employ an ARDL model to investigate the links between institutional quality, financial development, and renewable energy consumption, highlighting the importance of sustainable financial mechanisms.

Finally, several studies confirm the central role of institutional quality in reducing CO_2 emissions (Saboori et al., 2019; Azam, 2020; Salman et al., 2019). Khan et al. (2023) examine the combined effect of urbanisation and institutional quality, stressing the moderating role of government effectiveness. Overall, these studies illustrate the complex interactions between economic development, industrialisation, agriculture, and energy consumption, and advocate the implementation of integrated policies that promote renewable energy, energy efficiency, and sustainable agricultural practices in order to reduce Tunisia's carbon footprint.

4. Materials and methods

4.1. Data description

This study investigates the influence of socio-economic variables on CO_2 emissions in Tunisia, based on an annual time series covering the period from 1996 to 2023.

The variables considered in this study include per capita CO_2 emissions and institutional quality (INQ). Institutional quality consists of six indicators, namely: corruption control, government effectiveness, political stability and absence of violence or terrorism, regulatory quality, law rules, and voice and accountability. These indicators are combined using principal component analysis (PCA) to build a complex index (INQ). Other key variables incorporated into the analysis are agricultural value added (AGR), industrial value added (IND), non-renewable energy consumption (NREC), and renewable energy consumption (REC). To facilitate the interpretation of the results, all variables are expressed in natural logarithms. This transformation allows the interpretation of coefficients in percentage terms i.e., elasticities thus offering a clearer understanding of the relative impact of each variable on CO_2 emissions. The data are obtained from two primary sources, namely the World Development Indicators (WDI) and the U.S. Energy Information Administration (EIA). All simulations were conducted using the EViews 12 software package. Table 1 presents the definitions of the variables, data sources, and the units of measurement used in the analysis. In addition, Table 2 provides descriptive statistics for the variables, including the mean, standard deviation, and minimum and maximum observed values.

Table 1 – Description of the variables used

Variables	Abbreviations	Unit of Measurement	Source
CO_2 emissions	CO_2	(Tonnes per capita)	WDI[2]
Value added of agriculture (agriculture, forestry and fisheries)	AGR	(% of GDP)	
Value added of industry (industry including construction)	IND		
Institutional quality	INQ	Index	
Renewable energy consumption	REC	(QBTU)[3]	EIA[4]
Non-renewable energy consumption	NREC		

The descriptive statistics reveal significant variability among the variables under study. Per capita CO_2 emissions (LogCO2) have a mean of 0.846 with a standard deviation of 0.132, ranging from a minimum of 0.581 to a maximum of 1.013. Agricultural added value (Log AGR) shows a mean of -2.375 and a standard deviation of 0.139, with extreme values ranging from -2.681 to -1.987. Industrial added value (LogIND) has a mean of -1.336, a standard deviation of 0.094, a minimum value of -1.537, and a maximum of -1.157. Institutional quality (LogINQ) displays greater variability, with a mean of 0.653, a standard deviation of 0.302, and values ranging from -0.280 to 1.058.

[2] WDI: World Development Indicators.
[3] QBTU: quadrillion de British Thermal Units.
[4] EIA: The U.S Energy Information Administration

Table 2 – Descriptive statistics

Variables	LogCO2	Log AGR	Log IND	Log INQ	Log NREC	Log REC
Mean	0.846	-2.375	-1.336	0.653	-1.090	-6.217
Median	0.877	-2.376	-1.330	0.732	-1.098	-6.214
Maximum	1.013	-1.986	-1.156	1.058	-0.884	-4.509
Minimum	0.581	-2.681	-1.536	-0.280	-1.491	-6.907
Std. Dev.	0.132	0.139	0.094	0.302	0.153	0.718
Skewness	-0.580	0.344	-0.004	-1.157	-0.524	0.878
Kurtosis	2.046	3.869	2.361	4.548	2.844	3.108
Jarque-Bera	2.633	1.435	0.476	9.047	1.313	3.618
Probability	0.267	0.487	0.788	0.010	0.518	0.163
Sum	23.693	-66.501	-37.418	18.301	-30.528	-174.096
Sum Sq. Dev.	0.473	0.523	0.239	2.476	0.637	13.940

Source: Author's calculation (2025)

Non-renewable energy consumption (LogNREC) has a mean of -1.090, with a standard deviation of 0.153, and values ranging from -1.492 to -0.884. Finally, renewable energy consumption (LogREC) exhibits the greatest variability, with a mean of -6.218, a standard deviation of 0.718, a minimum of -6.908, and a maximum of -4.510. These results highlight notable differences in the distribution and magnitude of variations across the different variables.

5. Modelling and methodological framework

This study aims to analyse the relationship between CO_2 emissions (LogCO_2), institutional quality (LogINQ), the added value of the agricultural sector (LogAGR), the added value of the industrial sector (LogIND), renewable energy consumption (LogREC), and non-renewable energy consumption (LogNREC), based on data for Tunisia covering the period 1996–2023. Drawing on the methodologies proposed in previous studies (Çobanoğulları 2024; Saadaoui and Chtourou 2022; Rauf et al. 2018; Apergis et al. 2018; Zaidi and Saidi 2018; Cherni and Essaber-Jouini 2017) and taking into account the specific characteristics of our dataset, the most appropriate approach selected is the Autoregressive Distributed Lag (ARDL) model with bounds testing for cointegration, as introduced by Shin and Pesaran (1999) and formalised by Pesaran et al. (2001).This model allows a rigorous assessment of both short- and long-term dynamics between CO_2 emissions, institutional quality, the performance of the agricultural and industrial sectors, and the various forms of energy consumption in Tunisia. The adopted ARDL model is presented in equations (1) and (2).

$$\text{Log CO2} = f(\text{Log INQ, Log AGR, Log IND, Log NREC, Log REC}) \quad (1)$$

$$\text{Log CO2}_t = \alpha + \beta_1 \text{Log INQ}_t + \beta_2 \text{Log AGR}_t + \beta_3 \text{Log IND}_t + \beta_4 \text{Log NREC}_t + \beta_5 \text{Log REC}_t + \varepsilon_t \quad (2)$$

In equation (2), where t represents the years from 1993 to 2023, LogCO2 denotes the logarithm of carbon dioxide emissions, LogINQ the logarithm of institutional quality, LogAGR the logarithm of agricultural value added, LogIND the logarithm of industrial added value, LogNREC the logarithm of non-renewable energy consumption, and LogREC the logarithm of renewable energy consumption. The coefficients are denoted by β, α represents the constant term, and ε_t denotes the error term.

Table 3 – Findings of the ADF and PP tests

Variables	ADF				PP			
	(Level)		(First Difference)		(Level)		(First Difference)	
	t-stat	p-val	t-stat	p-val	t-stat	p-val	t-stat	p-val
Log CO2	1,648	0,972	-7,648 ***	0,000	2,075	0,988	-7,189 ***	0,000
Log AGR	-3,332 **	0,023	-6,297 ***	0,000	-3,332 **	0,023	-6,393 ***	0,000
Log IND	-3,332 **	0,023	-4,651 ***	0,005	0,618	0,843	-4,716 ***	0,000
Log INQ	-1,124	0,230	-4,885 ***	0,003	-1,120	0,230	-4,598 ***	0,001
Log REC	-0,522	0,480	-6,895 ***	0,000	-0,522	0,480	-6,759 ***	0,000
Log NREC	-1,795 *	0,069	-6,608 ***	0,000	-1,795 *	0,069	-5,969 ***	0,000
Critical values	(1%)	-2,656	(1%)	-3,711	(1%)	-2,656	(1%)	-3,711
	(5%)	-1,954	(5%)	-2,981	(5%)	-1,954	(5%)	-2,981
	(10%)	-1,609	(10%)	-2,629	(10%)	-1,609	(10%)	-2,629

Note: ***, ** and * indicate statistical significance at 1 %, 5 % and 10 % respectively.

Source: Author's calculation (2025)

An ARDL model can be employed because the variables are either I (0) or I (1), which constitutes a fundamental condition for the application of the ARDL approach. However, it is necessary to verify the presence of cointegration among the variables in order to confirm the existence of a long-term relationship prior to estimating the model. If cointegration is detected, the ARDL model will prove to be an appropriate tool for analysing both the short- and long-term dynamics among the variables.

6. The ARDL approach and bounds test

The Autoregressive Distributed Lag (ARDL) model, introduced by Shin and Pesaran (1999) and further developed by Pesaran et al. (2001), enables the analysis of simple cointegration relationships. One of its main advantages lies in its flexibility:

it allows a combination of variables that are stationary at level [I(0)] and at first difference [I(1)], without requiring that all variables be integrated of the same order. Due to this methodological flexibility, the ARDL approach is widely employed in empirical studies, including the present research. It constitutes an effective method for examining long-term relationships between variables. Consequently, equation (2) can be reformulated as an ARDL model with a constant term, as presented in equation (3) below:

$$
\begin{aligned}
\Delta \mathrm{Log\ CO2}_t = \beta_0 &+ \sum_{i=1}^{P} \beta_1 \Delta \mathrm{LogCO2}_{t-i} + \sum_{i=0}^{q} \beta_2 \Delta \mathrm{LogINQ}_{t-i} \\
&+ \sum_{i=0}^{q} \beta_3 \Delta \mathrm{LogAGR}_{t-i} + \sum_{i=0}^{q} \beta_4 \Delta \mathrm{LogIND}_{t-i} \\
&+ \sum_{i=0}^{q} \beta_5 \Delta \mathrm{LogNREC}_{t-i} + \sum_{i=0}^{q} \beta_6 \Delta \mathrm{LogREC}_{t-i} \\
&+ \beta_7 \mathrm{LogCO2}_{t-i} + \beta_8 \mathrm{LogINQ}_{t-1} + \beta_9 \mathrm{LogAGR}_{t-1} \\
&+ \beta_{10} \mathrm{LogIND}_{t-1} + \beta_{11} \mathrm{Log\ NREC}_{t-1} \\
&+ \beta_{12} \mathrm{Log\ REC}_{t-1} + \varepsilon_t
\end{aligned}
\tag{3}
$$

The Bounds test is used to determine whether a long-run relationship exists between the variables. The alternative hypothesis ($\beta_7 \neq \beta_8 \neq \beta_9 \neq \beta_{10} \neq \beta_{11} \neq \beta_{12}$)contradicts the null hypothesis ($\beta_7 = \beta_8 = \beta_9 = \beta_{10} = \beta_{11} = \beta_{12}$), which implies no cointegration. The null hypothesis is rejected if the estimated F-statistic exceeds the upper bound critical value I(1) for the number of explanatory variables (k), as provided by Pesaran et al. Conversely, the null hypothesis cannot be rejected if the F-statistic falls below the lower bound critical value I(0). The F-statistic indicates inconclusive evidence of cointegration if it lies between the I(0) and I(1) bounds. Alternative critical values for I(0) and I(1), better suited to small sample sizes, have been proposed by Narayan (2005).

The optimal lag lengths p and q in equations (3) and (4) are determined using model selection criteria, such as the Akaike Information Criterion (AIC) or the Schwarz Information Criterion (SIC). The optimal values of p and q correspond to the minimum information criterion value, whether AIC or SIC. Additionally, the model residuals should not exhibit serial correlation. The model with the highest R^2 value or the lowest information criterion is considered to provide the best estimation. Finally, the following equation estimates the short-run dynamics of the ARDL model, also referred to as the error correction model:

$$\begin{aligned}\Delta \mathrm{LogCO2}_t = \beta_0 &+ \sum_{i=1}^{P} \beta_1 \Delta \mathrm{Log\,CO2}_{t-i} + \sum_{i=0}^{q} \beta_2 \Delta \mathrm{Log\,INQ}_{t-i} \\ &+ \sum_{i=0}^{q} \beta_3 \Delta \mathrm{LogAGR}_{t-i} + \sum_{i=0}^{q} \beta_4 \Delta \mathrm{LogIND}_{t-i} \\ &+ \sum_{i=0}^{q} \beta_5 \Delta \mathrm{LogNREC}_{t-i} + \sum_{i=0}^{q} \beta_6 \Delta \mathrm{Log\,REC}_{t-i} \\ &+ \beta_7 \mathrm{Log\,CO2}_{t-1} + \beta_8 \mathrm{Log\,INQ}_{t-1} + \beta_9 \mathrm{LogAGR}_{t-1} \\ &+ \beta_{10} \mathrm{Log\,IND}_{t-1} + \beta_{11} \mathrm{Log\,NREC}_{t-1} \\ &+ \beta_{12} \mathrm{Log\,REC}_{t-1} + \lambda \mathrm{ECT}_{t-1} + \varepsilon_t\end{aligned} \quad (4)$$

The speed of adjustment parameter, also known as the error correction term coefficient ($ECT_{(t-1)}$) λ in equation (4), determines how quickly the series return to long-run equilibrium. The model is subjected to diagnostic tests to assess its validity, including tests for serial correlation, normality, functional form, and heteroscedasticity. Brown et al. employed stability tests such as the Cumulative Sum (CUSUM) and the Cumulative Sum of Squares (CUSUMSQ) to examine whether the coefficients in the graphical representations remain stable over time.

7. Empirical results

The main objective of this study is to provide empirical evidence on the impact of institutional quality (Log INQ), agricultural added value (Log AGR), industrial value added (Log IND), non-renewable energy consumption (Log NREC), and renewable energy consumption (Log REC) on carbon dioxide emissions (Log CO_2). The analysis follows several methodological steps: first, the application of the bounds testing approach to cointegration to examine the relationships among the variables across the full dataset; second, the presentation of both long-run and short-run estimation results; and finally, the assessment of model stability using the Cumulative Sum (CUSUM) and the Cumulative Sum of Squares (CUSUMSQ) tests.

The results of the bounds test for cointegration, presented in Table 5, show that the null hypothesis of no cointegration is strongly rejected. Indeed, the F-statistic, which reaches a value of 7.465, significantly exceeds the upper critical bounds (I (1)) at all conventional significance levels, thus confirming the existence of a long-run relationship among the variables under study. This cointegration relationship indicates that the variables are linked in the long term. Consequently, the use of an error correction model (ECM) is justified to analyse both the short-run dynamics and the long-run equilibrium relationships among these variables.

Table 5 – Results of the bounds testing approach to cointegration

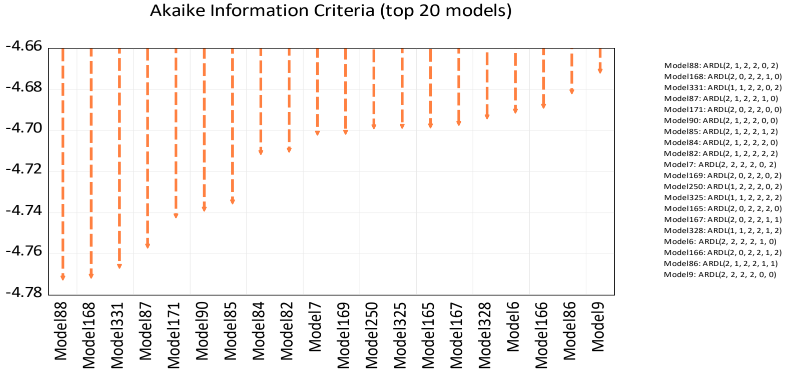
F-Bounds Test				
F-Bounds Test	Null Hypothesis: No levels relationship			
Test Statistic	Value	Signif.	I(0)	I(1)
Asymptotic: n=1000				
F-statistic	7.465	10%	2.08	3
K	5	5%	2.39	3.38
		2.50%	2.7	3.73
		1%	3.06***	4.15***
ActualSample Size	27	Finite Sample: n=35		
		10%	2.331	3.417
		5%	2.804	4.013
		1%	3.9***	5.419***
		FiniteSample: n=30		
		10%	2.407	3.517
		5%	2.91	4.193
		1%	4.134***	5.761***

Note: ***, ** and * indicate statistical significance at 1 %, 5 % and 10 % respectively.

Source: Author's calculation (2025)

The analysis reveals that, in Tunisia, there exists a significant long-run relationship between CO_2 emissions and institutional quality (INQ), agricultural added value (AGR), industrial added value (IND), non-renewable energy consumption (NREC), and renewable energy consumption (REC). Table 6 presents the long-run and short-run estimation results of the ARDL model (2,1,2,2,0,2), which was selected as the optimal model due to its lowest Akaike Information Criterion (AIC) value, as shown in Figure 5.

Figure 5 – Selection of optimal lag



Source: Author's calculation (2025)

In this analysis, CO_2 emissions serve as the dependent variable, explained by the following proxy variables: institutional quality (INQ), agricultural value added (AGR), industrial value added (IND), non-renewable energy consumption (NREC), and renewable energy consumption (REC).

Table 6 – Long-run and Short-run ARDL estimates

Long-run estimates				
Variables	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob**
Log INQ	-0.234***	0.052	-4.510	0.000
Log AGR	0.116	0.215	0.539	0.600
Log IND	1.241**	0.468	2.652	0.022
Log NREC	0.892***	0.152	5.848	0.000
Log REC	0.007	0.022	0.343	0.737
C	3.987**	1.326	3.005	0.012
Short-run estimates				
Variables	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
D (Log CO2 (-1))	-0.171	0.105	-1.615	0.134
D (Log AGR)	0.195***	0.051	3.794	0.003
D (Log IND)	0.574***	0.092	6.211	0.000
D (Log IND (-1))	-0.528***	0.095	-5.517	0.000
D (Log NREC)	0.198***	0.045	4.346	0.001
D (Log NREC (-1))	-0.184**	0.065	-2.824	0.016
D (Log INQ_)	-0.097***	0.019	-5.021	0.000
D (Log INQ (-1))	0.063**	0.022	2.863	0.015
ECT (-1)	-0.630***	0.070	-8.986	0.000

Note: ***, ** and * indicate statistical significance at 1 %, 5 % and 10 % respectively.
Source: Author's calculation (2025)

Institutional quality (Log INQ) exhibits a negative and statistically significant relationship with carbon dioxide emissions in both the long and short run. In the long run, a 1% improvement in the institutional quality index leads to a reduction of about 0.234% in carbon dioxide emissions, whereas in the short run, an equivalent improvement reduces emissions by around 0.097%. These findings, conform with the studies of Sekrafi and Sghaier (2025), Wang et al. (2022), Hamrouni et al. (2025), and Abbas et al. (2025), and can be attributed to strengthened regulations, enhanced institutional mechanisms, and more effective governance.

These elements limit the use of highly carbon-intensive inputs in favour of less polluting alternatives in Tunisia. They illustrate the positive impact of improved governance on environmental protection: more effective anti-corruption measures, greater government efficiency, increased political stability, stricter regulations. Besides, enhanced adherence to the rule of law contribute to reducing polluting practices, enforcing environmental standards rigorously, and overseeing high carbon dioxide-emitting sectors more efficiently, particularly energy-intensive industries and fossil fuel-dependent activities. The negative effect of institutional quality on carbon dioxide emissions in Tunisia, observed both in the short and long term, is confirmed by Sekrafi and Sghaier (2025), who highlight a significant relationship between corruption control and environmental quality. This pattern is also clear in other emerging economies in Africa, North Africa, and the MENA region. It indicates that the beneficial impact of institutions on emissions reduction extends beyond the national context and reflects a regional dynamic in which institutional reforms support environmental transition.

However, these positive effects are contingent upon the robustness of institutional frameworks e.g. economic liberalisation since when they are absent they may exacerbate environmental degradation. Surveys in ten emerging economies (Brazil, China, India, Russia, South Africa, Turkey, Mexico, Thailand, Egypt, and South Korea) confirm that institutional quality directly reduces carbon dioxide emissions (Hamrouni et al., 2025), as do Wang et al. (2022) for a panel of twenty-four African countries. For the MENA region, Abbas et al. (2025) show that institutional improvement across 21 countries, including Egypt, Morocco, and Tunisia, is associated with a decline in emissions in both the short and long term, while Saboori et al. (2025) specify that the majority of institutional indices, except for political stability and absence of violence, also contribute to this reduction. These findings are reinforced by Haldar and Seth (2020) for thirty-nine developing countries, including Tunisia, and by Obobisa (2022) for twenty-five African countries, demonstrating that institutional consolidation promotes both emissions reduction and sustainable development. On the other side, Obobisa et al. (2022) observe that, in certain countries such as Morocco, Egypt, and South Africa, some institutions may raise emissions by favouring energy-intensive growth policies with limited environmental constraints.

Non-renewable energy consumption (Log NREC) exhibits a positive and statistically significant relationship with carbon dioxide emissions, both in the long and short run. In the long run, a 1% increase in non-renewable energy consumption leads to an increase of approximately 0.892% in carbon dioxide emissions. In the short run, an equivalent increase results in a rise of around 0.198% in emissions. This finding is in conformity with the results of Ben Jebli and Ben Youssef (2016), Aguir Bargaoui, S. & Amri Amamou, S. (2020), and Shahbaz et al. (2014). In Tunisia, oil and natural gas remain the primary energy sources, and their direct use contributes significantly to the high levels of air pollution.

Similarly, the industrial sector elasticity is positive, high, and statistically significant in both the long and short run. In the long run, a 1% increase in industrial added value leads to an increase of almost 1.241% in carbon dioxide emissions, while in the short run, an equivalent rise results in an increase of around 0.574%. This finding confirms the energy-intensive and carbon-heavy nature of Tunisia's industrial sector, notably including the construction industry, which remains largely dependent on fossil fuels. These observations conform to the conclusions of Dallali and Ben Jebli (2025) and Ghazouani (2019), who emphasise the significant impact of industrialisation on environmental degradation in Tunisia. Moreover, the energy structure of the industrial sector, dominated by natural gas (38%) and petroleum products (37%), reflects a persistent reliance on high-carbon sources. Thereby it explains the sector's substantial contribution to national carbon dioxide emissions.

In contrast, while agricultural added value is positive (0.116), it is not statistically significant in the long run, suggesting that the sector does not have a structural influence on carbon dioxide emissions in Tunisia, given its limited energy contribution. However, in the short run, a 1% increase in agricultural added value leads to a 0.195% rise in emissions. This reflects the immediate impact of intensive farming practices, such as the use of machinery and energy-intensive inputs. Consequently, agriculture appears to have a transitory effect on emissions, in line with its modest share of national energy consumption (6.4% in 2023). This observation aligns with the short-run findings of Ben Jebli and Ben Youssef (2016), though it diverges in the long run.

Renewable energy consumption (Log REC) has a positive, and yet very limited and statistically non-significant effect, on carbon dioxide emissions in Tunisia. This suggests that, despite efforts to develop solar, wind, and hydro capacities, their contribution to total energy consumption remains low (11.4% of final consumption) and is not enough to reduce emissions in the long run significantly. This situation reflects the country's economic context, where renewable energies have yet to constitute a substantial alternative to fossil fuels. These findings are in conformity with the studies of Chaouali et al. (2023), Ben Jebli and Belloumi (2017), Apergis et al. (2010), and Nguyen and Kakinaka (2019), which demonstrate that the impact of renewable energy consumption on environmental degradation depends on a country's level of economic development. While, it can effectively reduce carbon dioxide emissions in high-income countries; it may conversely contribute to environmental degradation in low-income countries. In the short run, renewable energy consumption (Log REC) does not appear to be a significant determinant of carbon dioxide emissions, reflecting its minimal immediate effect, as it has a lag of zero in the selected specification (2,1,2,2,0,2). Consequently, its impact on carbon dioxide emissions is immediate and is not captured in the short-run dynamics of the explanatory variables.

Finally, the coefficient of the error correction term (-0.63) reveals a rapid convergence towards the long-run equilibrium, highlighting the economy's capacity to adjust quickly to shocks. These findings suggest that, in the absence of structural policies aimed at greener industrialisation and an accelerated energy transition, Tunisia will remain vulnerable to the environmental pressures linked to its development model. Diagnostic tests applied to the ARDL model are essential for assessing the validity, reliability, and robustness of the empirical estimates. The results, presented in Table 7, confirm that the model does not suffer from major econometric issues.

Table 7 – Diagnostic test results

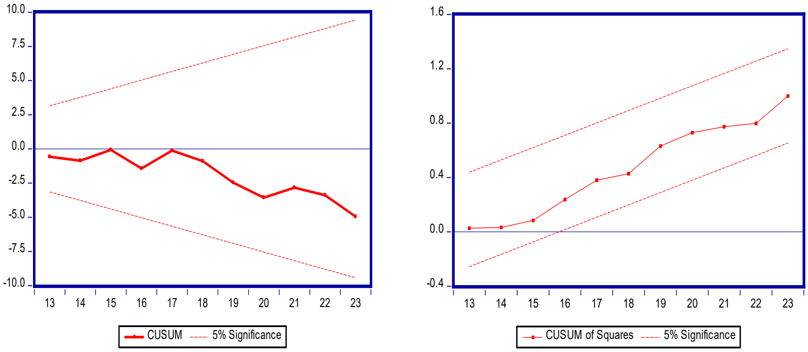
Test	F-Statistic	P-Value
Breusch-Godfrey Serial Correlation LM Test	0.366	0.703
Jarque-Bera Test	1.354	0.508
Breusch-Pagan-Godfrey-test	0.417	0.936
Arch-test	2.002	0.170
Ramsey rese-test	0.669	0.432
Chow break point-test	0.762	0.588

Note: ***, ** and * indicate statistical significance at 1 %, 5 % and 10 % respectively.
Source: Author's calculation (2025)

The Breusch-Godfrey test for residual autocorrelation yields an F-statistic of 0.366 with a p-value of 0.703, indicating no autocorrelation. The ARCH test produces a statistic of 2.002 (p = 0.170), showing no evidence of conditional heteroskedasticity. Furthermore, the Breusch-Pagan-Godfrey test yields a high p-value (0.936), confirming the homoscedasticity of the residuals. Residual normality is verified by the Jarque-Bera test, whose statistic of 1.354 with a p-value of 0.508 suggests that the errors follow a normal distribution. The Ramsey RESET test, with an F-statistic of 0.669 and a p-value of 0.432, confirms that the model is correctly specified. Finally, the Chow structural break test (F = 0.762; p = 0.588) reveals no structural instability in the model's coefficients. Taken together, these results indicate the robustness and reliability of the ARDL model employed.

The CUSUM and CUSUMSQ tests were conducted to determine whether any structural breaks exist in the time series, as illustrated in Figure 6. According to the results, the CUSUM (Cumulative Sum of Recursive Residuals) and CUSUMSQ (Cumulative Sum of Squared Recursive Residuals) statistics lie within the critical bounds at the 5% significance level, indicating that no significant structural break was detected during the study period.

Figure 6 – Stability assessment using the CUSUM and CUSUM of Squares tests



Note: ***, ** and * indicate statistical significance at 1 %, 5 % and 10 % respectively.
Source: Author's calculation (2025)

The CUSUM and CUSUM of Squares stability tests confirm the robustness of the model by showing that both its coefficients and the variance of its residuals remain stable over the analysed period. The CUSUM test, which assesses the stability of the estimated coefficients, indicates no major structural changes, as the curve remains within the 5% significance bounds. Similarly, the CUSUM of Squares test, used to detect possible variations in the variance of the residuals, reveals no significant instability. These results indicate that the model maintains a coherent and reliable structure over time, thereby reinforcing the validity of the estimates obtained and their relevance to the analysis conducted. Consequently, the absence of structural instability ensures that the relationships identified by the model remain robust and interpretable throughout the entire study period.

8. Conclusion and policy implications

The empirical analysis in this study has highlighted the impact of institutional quality, agricultural and industrial added value, as well as energy consumption (both renewable and non-renewable) on CO_2 emissions in Tunisia, both in the short and long term. The findings of this study indicate that institutional quality alone exhibits a negative relationship with CO_2 emissions, contributing to their reduction in both the short and long term. In contrast, the main factors drivers of increased CO_2 emissions over both periods are industrialisation and non-renewable energy consumption. However, the contribution of agriculture to CO_2 emissions is only short-term, reflecting the immediate effects of intensive farming practices, such as the use of machinery and energy-intensive inputs. This is due to the relatively low share of fossil fuel use in comparison to sectors such as industry and transport. The impact of renewable energy consumption remains negligible, largely due to the current insufficiency of renewable sources as a viable alternative to fossil fuels, as their share in total energy consumption remains too limited to achieve a substantial reduction in CO_2 emissions.

The results of this study indicate that institutional reforms in Tunisia can play a pivotal role in reducing carbon dioxide emissions. Indeed, corruption control ensures the efficient use of resources allocated to environmental protection and helps limit polluting practices. Government effectiveness facilitates the swift and coherent implementation of environmental policies, while political stability and the absence of violence or terrorism create a conducive environment for investment in clean technologies and low-carbon infrastructure. Regulatory quality establishes strict environmental standards and promotes sustainable economic practices. Moreover, the fact of adhering to the law rules ensures their effective enforcement and the sanctioning of perpetrators. Finally, citizen participation and democratic accountability (voice and accountability) encourage individuals and businesses to adopt environmentally responsible behaviours. Together, these institutional dimensions strengthen environmental regulations and enhance energy efficiency. Additionally, they promote the adoption of clean energy sources, and contribute to the sustainable reduction of carbon dioxide emissions.

These study findings have significant policy implications for Tunisia, and highlight the need to strengthen governance and institutional quality in order to achieve low-carbon sustainable development objectives. Priority recommendations include promoting environmentally-friendly agricultural and industrial practices, investing in modern energy infrastructures particularly solar energy, given the country's substantial solar potential as well as developing renewable energy sources and biomass. It is essential to ensure the strict implementation of environment standards, empower democratic institutions and the law rules, and preserve natural resources through rigorous anti-corruption measures. It is also vital to diversify energy sources, and improve national energy efficiency.

Policymakers should also boost Tunisian enterprises to adopt concrete measures so as to reduce pollution, rehabilitate and upgrade existing pollution-control facilities, and adopt clean technologies financed according to the value of environment investments. Awareness-raising among producers, firms, and citizens regarding the use of renewable energy and the reduction of polluting practices represents an additional lever for action. The Tunisian state must also issue and enforce regulatory directives effectively. For instance, emission quotas and mandatory filtration systems for the most polluting installation are supported by the Tunisian Pollution Control Fund (FODEP, 1995). Implementing these measures will contribute to reducing carbon dioxide emissions, expanding renewable energy use, and strengthening Tunisia's environment resilience. Future research could build on these findings by examining, in a more disaggregated manner, the various indicators of institutional quality and their effects on carbon dioxide emissions. Meanwhile, they might also incorporate further relevant variables such as transport, services, and tourism in the Tunisian context or in other developing countries.

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