

Digital growth in Algeria and its implications on the economy and the environment: Analysis using the ARDL approach for the period 2000-2022

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Summary: This article assesses the impact of digital growth in Algeria and its implications on the economy and the environment. For a more aggregated use of ICT, it addresses the hypothesis of the rebound or the third-order effect, implied by the electricity consumption channel. This contribution deploys a constructive, conceptual, and quantitative analysis. Referring to the empirical work of Hilty et al. (2006) and Tsaurai et al. (2019), we estimate an ARDL model to examine the short-and long-term elasticity coefficients of electricity consumption, digital, economic, and financial growth indicators. The analysis spans from 2000 to 2022. The results indicate the presence of a co-integration form with an adjustment coefficient of -2.78 and a causality relationship between CO₂ emissions and the variables. The short-and long-term elasticity coefficients for per capita electricity consumption are negative. The coefficient is (-0.27) in the short term and smaller in magnitude in the long term (-0.147). The emissions rate per kWh has significantly decreased. The increase in electricity consumption is associated with a decrease in its carbon content. Moreover, digital indicators had a negligible effect with coefficients near zero. These results disprove the rebound effect and suggest that environmental sustainability improved in Algeria during the study period.

Keywords: Rebound effect; ICT sector; Carbon dioxide emissions; Algeria.

JEL Classification Codes: C51; Q51; Q54.

I-Introduction:

Nowadays, the growth of communication and the renewal of ways of conceptualizing and organizing economic activities have been boosted by the use of computers and digital technologies. The transformation has shifted value-creation professions to a new model of virtual and digitalized socio-economic development. In Algeria, the use of digital technology and its social and economic adoption are progressing rapidly. The country recorded growth in the number of users of digital devices and services. The importance of digital technology is emerging as a tool of communication and the revival of modes of use, exchange, and consumption in modern societies. In an obvious mobilization of channels favoring solutions in digital interaction modes, the digitalization of the economy has implied the deployment of alternatives, exploding the use of digital means. Since the onset of the “Covid-19” health crisis, IT and virtual transaction methods (digital payment) have recorded significant growth. In this context, we examine the impact of digital growth on the economy and the environment and explore the main aspects covering the orientations of the needs of societies towards accelerated and digitalized modes. In this wake, we are trying to understand whether this deployment driving an unprecedented shift towards digital modes of organization has led to environmental impacts subjugated by the efforts to digitize economic and commercial activities and the introduction of efficient technologies in terms of energy and materials consumed (efficiency and energy savings). Referring to the empirical work developed by Hilty, L-M., Arnfalk, P., et al. (2006) and Tsaurai, K. and Chimbo, B. (2019), we take a quantitative approach through ARDL time series modeling covering the years from 2000 to 2022. In this model, we estimate the influence of digital growth indicators (growth in the subscriber base in the ICT sector and revenues generated) and account for the effects of emissions from imported and exported trade transactions.

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We take into account the hypothesis of the rebound effect, or the third-order effect, caused through the electricity consumption channel. This contribution uses a constructive and documentary research methodology and utilizes a conceptual and quantitative analysis.

The results from the ARDL model estimation over the period 2000 to 2022 confirm the existence of a long-term relationship. The Form co-integration estimation reveals a significant adjustment coefficient, demonstrating that per capita carbon dioxide emissions are adjusted annually by 2.78. The relationship between carbon dioxide emissions and per capita electricity consumption shows a negative coefficient in both the short and long term. The elasticity is (-0.27) in the short term and (-0.147) in the long term, indicating a lesser magnitude in the latter case. This negative and inverse relationship shows that the increase in electricity consumption is accompanied by a reduction in its carbon intensity. The emissions rate per kWh decreased due to the fuel savings obtained by the introduction of the combined cycle power plants characterized by low average specific fuel consumption. Furthermore, the digital indicators have a smaller effect in the short and long term (the effect is negligible).

The Granger causality test indicates a unidirectional relationship between carbon dioxide emissions and per capita electricity consumption, GDP, and fixed and mobile telephony turnover. In terms of consumption of energy, the introduction of efficient technologies has contributed to a decrease in the carbon footprint. Financial and economic growth indicators are channels that promote environmental sustainability.

I.1. Digital transformation and its implications on the economy of Algeria: a rapidly expanding process

In November 2023, the Algerian population is estimated at 44.16 million inhabitants. The national rate of ownership of a mobile phone is around 110%. Every Algerian has more than one mobile phone. More than two-thirds of Algerians subscribe to the internet, or around 35.7 million people. The usage rate of social networks is around 54%, or nearly 24 million people active on social media.

Table (1): Evolution of the subscriber base and ICT income (Algeria)

	Fixed telephone subscribers	Mobile phone subscribers	Fixed broadband internet subscribers	Income of fixed and mobile telephony (billion DA)
2000	1761000	86000	0	21
2020	4785763	45555670	3790459	391.92
2023	6324384	51522147	5530000	481.05

The source: Established by the authors from data extracted from the Annual Report of the Algerian Postal and Electronic Communications Regulatory Authority ARPCE (2010), in <https://www.arpce.dz/fr/file/r3s8q6>, p.11, and the Annual Report of ARPCE (2023), in <https://www.arpce.dz/fr/file/o3x8z4>, pp.1-13.

The growth in the digital ownership rate implies a spectacular growth in the number of mobile and internet subscribers compared to fixed telephone subscribers. The number of mobile and broadband internet subscribers increased, respectively, from 0 fixed broadband internet subscribers in 2000 to 5.53 million subscribers in 2023 and from 86,000 mobile subscribers in 2000 to nearly 5.2 million subscribers in 2023.

The number of fixed telephone subscribers increased from nearly 2 million in 2000 to 6.3 million in 2023. This exponential growth in the number of subscribers in the ICT sector has brought back revenues in the sector (mobile telephony and fixed) from 21 billion DA in 2000 to 481.05 billion DA in 2023. The analysis of the ownership rate of digital devices in Algeria indicates a loss of market share for the use of laptops, which went from 99% in 2009 to 44.59% in 2023. With the economies of scale recorded in the mobile phone industry in the world, the acquisition of smartphones becomes an alternative, making their uses a multi-function tool. The mobile phone has regained a considerable market share. It has increased from 0.14% in 2009 to 53.59% in 2023. In Algeria, preferences for smartphones are changing organizational and communication methods by making the mobile phone an essential pocket tool. As for the tablet market, the latter has relatively declined from 3.77% in 2015 to 1.82% in 2023.

1.2. The legal framework for digital activities in Algeria: What impact on the development of electronic banking?

In Algeria, the rise of digital communication and IT technologies has played a crucial role in the integration of digital technology into the payment system, which has been anchored for a long time in the culture of preferences to pay in cash. The large-scale development of electronic payment instruments (banking instruments) remains behind, although the digital transition continues to require its adoption as a tool for modernization and economic development. The growth of electronic banking and its use in cashless payment methods was driven by the execution of transactions carried out via the interbank electronic network, boosted by eight public banks and twelve other financial and banking establishments, particularly in the private sector. In Algeria, law has lagged behind in introducing the legal environment appropriate to the revival of e-commerce and the use of electronic payment instruments. Indeed, the legal framework for digital commerce activities has taken a step back to identify the real issues of more generalized modernization. Thus, Law No. 2000-3 relating to post and telecommunications (law amended in 2018), Law No. 05-01 relating to the fight against money laundering, Law No. 09-04 relating to the fight against ICT-related offenses, and Law No. 15-4 relating to electronic signature and certification have only contributed to strengthening the security of platforms governing networks, electronic banking, post, and telecommunications.

The launch and development of digital activities and the strengthening of their uses in public administrations and society were materialized by the establishment of the project of e-Algeria 2013 and the introduction by SATIM, “company for automating interbank and monetary transactions,” of a technical device allowing electronic payments relating to purchases on e-commerce sites to be made using local bank cards (Jankari, R., 2014, pp. 18-19). Indeed, the public sector has set itself the objective, over the period 2009 to 2013, to accelerate the use of ICT and the generalization of the modernization of public administration (Summary document, 2008, pp. 13-31).

By ensuring the interoperability of the interbank electronic system at the national and international level, the development of e-payment should contribute to improving the banking rate, which is struggling with the growth of the financial system. In 2018, Algeria had an average of 5.3 bank branches per 100,000 inhabitants and recorded 9,204 ATMs (automatic teller machines) for each adult. By revitalizing electronic commerce, the use of banking and financial institutions should increase the number of direct debits and bank accounts. Algerian legislation requires, for cross-border e-commerce transactions, the domiciliation of the e-supplier with an Algerian bank or the post office. Currently, the penetration rate of electronic banking in Algeria is very low, which should push the Algerian authorities to take the following measures:

- To increase the penetration rate of electronic banking by increasing the number of EPIs (Electronic Payment Instruments) and automatic teller machines. In this regard, merchants are required to comply with Article 111 of the finance law of 2020, requiring merchants to make electronic payment instruments available to consumers before December 31, 2020.
- Raise awareness among merchants to integrate electronic banking as a preferred payment method through the use of EPIs.
- Improve the banking rate of the economy by intensifying the network of banking agencies and rebalancing their geographical distribution.
- Ensuring that citizens are brought closer to administration and business by providing them with secure access to the Internet to pay their bills.
- Fight against cybercrime by protecting the e-consumer through regulations.
- Fight against Internet user fraud by establishing regulations that cover transactions even on an international scale.

1.3. Digital transformation in trade and services activities in Algeria

The bank card is essential to settling transactions in cashless mode. The first withdrawal operation via the ATM was used in 1997, while the first use of an electronic payment terminal dates from 2005. These instruments, whose first global uses dated from the sixties and seventies, remained insufficient in number to promote a massive revival of e-commerce in Algeria until 2019. In terms of volume, the use of electronic banking has evolved over time but remained relatively behind when compared to the electronic banking system in other countries. The number of bank

cards increased from 472 thousand in 2009 to more than 16 million cards in 2023. The number of ATMs increased from 572 ATMs in 2009 to 3,847 in 2023. At the end of 2023, the number of payment terminals in different businesses increased from 2639 terminals to 51191. In Algeria, according to the e-commerce index, the digital economy was classed on a global scale at 111th place in 2018 and 107th place in 2019 (a gain of 4 places).

Table (2): Evolution of bank card transactions passing through the ATCI system

	2009	2016	2018	2019	2023
Number of payment cards	472000	804674	619624	9620000	16510000
Number of ATMs	572	593	1441	1621	3847
Number of EPIs	2639	5049	15397	23762	51191

The source: Established by the authors using data from the Bank of Algeria reports: 2016, 2018, and 2023 and GEI in <https://giemonetique.dz/cartes/>

To further revitalize the digital economy, in June 2014, a new body called GIE (electronic banking economic interest group) was set up. The latter seeks to ensure effective regulation of the interbank monetary system through interoperability with electronic banking systems at the national and international levels. With the launch of the new electronic banking management system in 2016, the country witnessed the first operations to bring citizens closer to companies and businesses. There is a launch of online service purchasing operations (telephone services purchasing units, travel insurance subscription services using CIB cards, airline ticket purchasing services, water, electricity, and gas bill payment services, etc.). From January 2020, we are witnessing interoperability of the interbank electronic system with the Algerian postal system. Holders of postal (Edhahabia) and bank (CIB) electronic payment cards can carry out withdrawal operations via ATMs connected to banks and post offices. The online transactions and payments have shown the effects of the generalization of digital technology. Thanks to the efforts made and the facilitations introduced recently to ensure fluidity in accessing the online payment system. The number of web merchants joining the platform increased from 9 in 2016 to more than 475 participants in 2023. In Algeria, the health crisis constituted a condition for spontaneous delivery using electronic transactions. The volume of online payment transactions highlights a large-scale deployment in record time compared to previous years. From 2016 until November 2023, the number of online payment transactions experienced average annual growth exceeding 5%. The volume of online payments increased from 7366 transactions in 2016 to more than 15.35 million in 2023. The value of online payments increased from 18.15 billion DA in 2016 to more than 32.2 billion in 2023. These transactions have recorded a considerable increase from 2019, in particular through the introduction of online administrative services such as CNAS, commercial registers, etc., which recorded in 2019 approximately 2,0432 payment transactions and provision of services (hotel services, travel and visa fees, etc.) with 5,056 payment transactions (see appendices, table 9).

Table (3): Evolution of payment activities on EPIs

	<i>Number of EPIs</i>	<i>Number of transactions</i>	<i>Transaction amount</i>
2017	11985	122694	861775368.9
2018	15397	190898	1335334130.76
2019	23762	274624	1916994721.11
1 st half of 2020	35192	168824	1137879706.42
2 nd half of 2020	35192	413848	2774332474.58
2023	51191	4 Million	31520000000

The source: Established by the authors from data extracted from www.giemonetique.dz

With the increase in online payments in the fields of transport (SNTF, Air Algeria, etc.), telecommunications, energy, and water, the total amount of online payments increased from 332.592 million DA in 2018 to 503.870 million DA in 2019. The COVID-19 pandemic has created an urgent need for the use of online payments. The pace of transactions has accelerated, causing the total number and value of online payment transactions to explode. In 2020, the number of online payment transactions increased from more than 1.52 million transactions for an amount of 1.881

billion DA in the first half of the year to 2.46 million transactions with an amount of 2.86 billion DA recorded during the second half (until November). An increase in volume of 18.7% was recorded compared to 2019, of which 24.82% concerned the payment of invoices to telecommunications services (purchases of telephone, internet, and other units), 34.64% was in the field of service provision, 26.96% was in administrative services, and finally, the introduction of web merchants was intended for online sales of goods whose volume reached 193 transactions during the year 2020. In 2023, the total volume and value of online payment transactions will more than double. The number of transactions increased from 4.5 million transactions carried out in 2020 to 15.35 million in 2023, bringing the total amount of transactions from 5.4 billion DA in 2020 to 32.2 billion DA in 2023. Payment transactions carried out via EPIs have experienced considerable growth in volume and value. A growth in volume of 112.17% was recorded during the months of confinement compared to the year 2019, compared to 43.86% between 2019 and 2018. The use of EPIs is explained by the remarkable increase in their number. The latter increased from 23,762 in 2019 to 35,192 until November 2020, an increase of 48.1% (11,420 EPIs set up over the course of one year). The health crisis has had a considerable effect on the use of EPIs and ATMs. The use of EPIs resulted in an amount of 3.912 billion DA in 2020 compared to 1.917 billion DA in 2019. There is an increase in value of more than 104% during the pandemic compared to 43.56% for the previous period. At the ATMs, withdrawals increased to 9.92 million transactions for an amount of more than 189 billion DA. In 2023, the number of EPIs increased to 51,191. The number of transactions carried out is around 4 million for an amount of 31.52 billion DA.

I.4. Digital pollution: concept and literature review

Digital pollution refers to the environmental impact linked to the use of computers and digital technologies. It relates to the effects attributed to the use of digital devices throughout their life cycles until their disposal. Certain visions support the positive effect of technological progress and the advantages of the introduction of intelligent innovations and ICT. On the level of carbon dioxide emissions, the world will avoid 20% of GHGs in 2030. Provision of 10 times fewer emissions (Smarter, 2030, Report, 2015, pp. 8-9). Other authors raised a harmful ripple effect caused by the orientation of ICT uses towards other new energy-intensive demands. These latter lead to increasing the use of digital technologies and the extension of mobile and internet network infrastructures. In the scenario of maintaining the energy efficiency policy (sobriety), this rate (GHGs emissions) would settle at less than 5% with an average annual growth of 8% in 2025. In the scenario of the absence of energy sobriety, this rate could exceed a share of 8% in 2025. (The Shift project 2020, pp. 14-15). Bekaroo, G., Bokhoree, CH., and Pattinson, C., showed the dissipated effect of ICT on the reduction of carbon dioxide emissions. These authors confirmed the hypothesis of the high carbon footprint of the ICT sector, which is mainly attributed on a global scale at 57% to digital assets, 25% to network infrastructures, and 18% to data centers. Although ICT was seen as a catalyst for carbon emissions, its widespread use contributes to an increase in energy consumption and therefore greater carbon emissions (Bekaroo, G., Bokhoree, CH., and Pattinson, C., 2016, p. 1580). In France, the report from the digital transition agency ADEM and the Regulatory Authority for Electronic Communications, Posts, and Press Distribution ARCEP revealed the results of the analysis of the environmental impact of digital technology. This impact and prospective analysis revealed that on the global scale, ICT contributes to carbon dioxide emissions with a carbon footprint estimated at around 16.9 MtCO₂ eq. (Mt CO₂ eq.: a million tons of carbon dioxide emissions equivalent). On an individual scale, each French person is responsible for a carbon footprint estimated at 253 kg carbon dioxide emissions (ADEM Report, ARCEP, 2022, pp. 94-130).

Koppn, Th., and Lange, S. (2019) examined the relationship between digitalization and environmental indicators, particularly the effects associated with production and consumption activities of goods. Through a PANEL model made up of 37 OECD countries analyzing consumption data spread from 2008 to 2014 and production data covering the years 1990 and 2009, the authors proceeded to redistribute the analysis of environmental impact into two effects linked to production and consumption. The first led to positive impacts linked to the integration of ICT in the goods production process. This effect depended on the level of GDP. For consumption, digitalization implies a reduction in the effect on the environment. This effect evolves inversely with the increase in GDP (Kopp, Th., and Lange, S. 2019, pp. 1-6). Hirschier, R., Coroama, V-C., et al. (2015) analyzed the impact of ICT on the environment through the life cycle analysis method.

The authors showed that one hour of digital use by end users would have a direct or indirect effect on the environment, assuming that these devices were used two hours per day (Hischier, R., Coroama, V-C., et al. 2015, pp. 94-130). Suckling, J., and Lee, J. (2015) analyzed the impact of smartphones on the environment by examining greenhouse gas emissions (GHG) during the different phases of a cell phone's life cycle. The study showed that during its manufacturing, the smartphone has a very high carbon footprint compared to the other phases. This carbon footprint of the smartphone can increase when it is connected to a server. It can vary from 8.5 to 18.0 kg carbon dioxide emissions equivalent. When connected to a network, smartphones generate additional emissions of 24.7 kg of carbon dioxide emissions equivalent. By focusing on the analysis of peaks in data transfer flows via digital technology and their alignment with peaks in electricity consumption, researchers Morley, J., Widdick, K., and Hazas, M. (2018) supported the thesis that during peak hours, the excess electricity consumed by data transmission networks, particularly exchanged via digital networks, potentially amplifies the peak consumption and contributes to the increase in demand for electricity during critical hours of the day, particularly in the evening (Morley, J., Widdick, K., Hazas, M., 2018, pp. 130-136). Heddeghem, W-Van., Lambert, S., et al. (2014) analyzed the consumption of electricity associated with the use of ICT equipment in the use phase from 2007 to 2012. The results of their estimation showed that the total electrical energy consumed by the three elements (networks, laptops, and data centers) increases annually by approximately 7%, or a doubling every 10 years (Heddeghem, W-Van., Lambert, S., et al. 2014, pp. 1-13). The work of Tsaurai, K., and Chimbo, B. (2019) has raised the importance of ICT in emerging countries and its impact on the rate of carbon dioxide emissions. Spreading their study over the period 1994-2014, the authors examined data from more than 20 emerging countries, notably the influence of financial indicators, economic growth, and trade openness and investment flows considered as channels by which the introduction of ICT leads to a reduction in carbon dioxide emissions. By developing a panel model, the authors showed that financial and economic growth indicators (means of development of ICT infrastructure) are channels through which the influence of ICT is favorable to the reduction of carbon footprints (Tsaurai, K., Chimbo, B., 2019, pp. 321-324). Kohler, A., and Erdmann, L. (2004) examined the impact of the development of ICT equipment on the environment. The authors developed the hypothesis that ICT can both lead to an increase in demand for energy and materials and risks of toxicity and pollution attributed to the environment. Furthermore, the first-order effect can be canceled out by the energy sobriety policies provided by the use of efficient and effective digital technologies. The authors raised the importance of the rebound effect caused by the appearance of new, highly developed service offerings that can counterbalance the effect of the use of ICT. Through their scenarios, the authors identified uses of ICT that could have a strong impact on the environment by modifying the quantity and quality of waste generated. (Kohler, A., Erdmann, L., 2004, pp. 831-845). The authors Hilty, L-M., Arnfalk, P., et al. (2006) demonstrated the impact of ICT on environmental sustainability. Through quantitative estimates and scenarios, researchers have shown impacts at three levels (Hilty, L-M., Arnfalk, P., et al., 2006, pp. 1619-1629):

- A first-order effect through the waste disposal sites generated by ICT during their life cycle (electronic waste).
 - A second-order effect through energy efficiency and energy savings provided by the use of efficient and clean technologies.
 - A third-order effect resulting in a shift from products to virtual services, which have become less energy-intensive in terms of energy and materials (switching from products to services, such as the use of intelligent technologies in efficient applications, in the case of intelligent heating systems, smart meters, the introduction of ICT in the work sector: mobile or remote working, etc.).
- As a result, the authors concluded that the harmful impacts of ICT on the environment are small and that at the global level, the two effects tend to be subtle and cancel each other out.

Amayed, Y. (2025) analyzed environmental quality in North Africa using an ARDL model. These results showed that fiscal measures and energy policies had an impact on environmental sustainability in these countries (Amayed, Y., 2025, p. 13).

II- Methods and Materials:

In this work, we evaluate the economic impact of digital growth in Algeria and its implications on the environment. We take a quantitative approach through ARDL time series modeling covering the years from 2000 to 2022 by using the EViews 9 software.

For a more aggregated use of ICT, we demonstrate (or invalidate) the hypothesis of the rebound effect, or the third-order effect, implied by the electricity consumption channel. Referring to the empirical work of Hilty, L-M., Arnfalk, P., et al. (2006) and Tsaurai, K. and Chimbo, B. (2019), we are assuming the two hypotheses enumerated below:

Hypothesis 1: The unprecedented shift towards digital modes of organization results in rapid growth in the number of subscribers and therefore in the income generated by the ICT sector. Furthermore, this phenomenon has involved technological deployment, particularly new, highly developed services and efficient, less energy-consuming, miniaturized technologies, such as smartphones. In addition to this positive effect of the digitalization of the economy, we support the idea that these modernization efforts have been accompanied by an energy efficiency policy (energy-saving, efficient, and less polluting technology introduced in electricity production activities, etc.) and the fight against global warming.

Hypothesis 2: By accounting for the growth of per capita GDP and the flow of income (turnover of the ICT sector), we assume that the economic and financial indicators are channels of ICT development and reduction in the emissions of carbon dioxide (thesis of Tsaurai, K., and Chimbo, B., 2019).

II-1 Description of model variables:

For financial and economic growth indicators:

CATIC: Fixed and mobile telephony turnover (expressed in billions of dinars).

PIBCAP: Per capita Gross domestic product (expressed in constant local currencies, DA).

ICT revenue data (CATIC represents the turnover of fixed and mobile telephony). These data are taken from the annual report of the Algerian postal and electronic communications regulatory authority ARPT of 2010 (data from 2000 to 2010) and ARPTE of 2022 for data from 2011 to 2022. GDP per capita data is extracted from the World Bank database for 2022.

Subscriber base growth indicators:

ABONTELMOBILE: The number of mobile telephone subscribers.

ABONTELFIXE: The number of fixed telephone subscribers.

ABONINTERNETHAUTDEBFIXE: The number of fixed broadband internet subscribers.

Indicators of ICT trade, energy consumption, and pollution emissions:

EXPOTIONSERVICETIC: Exports of ICT services. These data are expressed as a percentage of total export services.

IMPOTIONDEBIENTIC: Import of ICT Goods.

EMISSCOTMHAB: Per Capita carbon dioxide emissions expressed in millions of tons.

CONSOMMELEHABKWH: Per capita electricity consumption expressed in kilowatt-hours.

Imports of ICT goods expressed as a percentage of national GDP.

All data relating to pollution, trade, and energy consumption indicators cover the years 2000 to 2022 and are extracted from the World Bank database and Bank of Algeria.

Exports of ICT goods and imports of ICT services: These two variables are not integrated into the model since their contributions are very negligible and close to zero.

III-Results and discussion:

The choice of the ARDL model is justified by its performance as a dynamic model, making it possible to estimate the short-term effects exerted by the independent variables on the dependent variable as well as the verification of the presence of a long-term equilibrium relationship between these variables. The use of the ARDL model is very practical for small samples and time series whose variables are stationary at different levels, which corresponds to the case of the model studied in this study. The results show that the variables are not stationary and integrated in the same order. This result favors and justifies the choice of using an ARDL model. The electricity

consumption and the financial and growth indicators are expressed in logarithms to refine the figures and make the results easier to read. We use the Phillips-Perron unit root test to analyze the stationarity of the variables (see appendices, table 10). The Akaike Information Criteria and Schwarz (SCH) test are used to retain the appropriate number of lags and the most appropriate model. In this case, we opt for ARDL (2, 1, 1, 0, 1, 1, 0, 1, 1) with a linear trend. The results of the first estimation show the short-term impacts. The analysis of the elasticity coefficients indicates that the variables expressing digital growth and the per capita electricity consumption impact the carbon dioxide emissions variable in the short term (the probabilities associated with the elasticity coefficients are less than 5%). In order to evaluate the statistical quality of the model, the analysis of the R-squared and DW is indispensable. The coefficients show a high R-squared equal to 0.999345 and an F statistic = 269.0495 (probability = 0.000325 < 5%). The Durbin-Watson statistic DW=2.692092 shows the absence of autocorrelation (see appendices, table 11). The results of the ARDL estimation (2, 1, 1, 0, 1, 1, 0, 1, 1) must be validated by the co-integration and the bounds test in order to detect a long-term relationship. These tests can lead us to other estimations through the error correction model (ECM), which allows us to identify the results (short- and long-term estimations) that can be retained in this econometric study. The bounds test confirms the presence of a long-term relationship between the variables of the model. The F-statistic is given at 5.273813, which is greater than the most important limit of the critical value bounds at the confidence threshold of 1%, which is 4.43 (refer to the table relating to the tests). Analysis of the Form co-integration estimation table shows a significant adjustment coefficient with a probability of 0.0028, less than 5%, and a negative coefficient (-2.789). This figure indicates that the carbon dioxide emissions per resident adjust annually by 2.78 and confirms the presence of a long-term relationship. The carbon dioxide emissions variable has a positive impact on its value lagged one year. On an individual scale, each 1% increase in emissions emitted over the past year implies an increase of 0.57% in emissions over the following year (a cumulative effect).

Table (4): Estimated short-term relationship (co-integrating form)

Variable	Coef	Std. Error	t-Statistic	Prob.
DLOG(EMISSCOTMHAB(-1))	0.5739	0.113413	5.061011	0.0149
DLOG(CONSOMMELEHABKWH	-0.2760	0.071778	-3.846019	0.0310
D(ABONTELMOBILE)	0.0000	0.000000	2.788902	0.0685
D(ABONTELFIXE)	-0.0000	0.000000	-3.040807	0.0558
D(IMPOTIODEBIENTIC)	-0.028	0.011709	-2.395276	0.0963
D(ABONINTERNETHAUTDEBFIKE)	0.0000	0.000000	3.510379	0.0392
DLOG(CATIC)	0.1154	0.057136	2.021103	0.1365
DLOG(PIBCAP)	1.1005	0.608358	1.809049	0.1682
D(@TREND())	0.0499	0.010804	4.620183	0.0191
CointEq(-1)	-2.789	0.307596	-9.069347	0.0028

The source: Established by the authors using Eviews9 software.

The growth of digital indicators had a very small impact on GHG emissions. The short-term effect is very negligible. The regression coefficients are zero. There is a negligible impact on the environment. The short-term impact of per capita electricity consumption is negative. Each 1% increase in electricity consumption per capita results in a 0.27% reduction in GHG emissions. The carbon footprint caused by the consumption of one kilowatt-hour per individual has decreased considerably from 2009. The annual growth rate of carbon dioxide emissions decreased from 2.73% in 2009 to 2.34% in 2017, then to -6.91% in 2019 and -0.25% in 2022. This observation is similar to the annual growth of per capita electricity consumption, which recorded a clear decline from 2009. Indeed, the rate of annual growth fell from 17.37% in 2009 to 6.61% in 2013, then to -4.48% in 2019 and 1.25% in 2022. The slowdown and decline in the growth rate of GHG emissions in Algeria is explained through energy efficiency policies undertaken since the promulgation in 1999 of the law relating to energy management and energy efficiency through the control of devices operating on the basis of particularly polluting fuels, as well as the ratification of several international conventions aimed at the fight against global warming. In this context, electricity consumption has had a significant impact on carbon dioxide emissions, leading to the control of GHG emissions (energy efficiency in all sectors, introduction of efficient technologies in cogeneration activities, control of devices operating on polluting fuels, introduction of efficient

technologies in homes: intelligent heating, appliances labeled low consumption, low-consumption bulbs, digitalization of services and administrations, etc.). Furthermore, the effect of electricity consumption on the GHG emission rate is not direct. It is observed during the activity of production through the use of polluting fuels. This pollution is even more significant at peak consumption times, when fast-start power plants, particularly diesel-type, are called in and used. Furthermore, we note that Algeria acquired, during the study period, new efficient power plants, consuming less energy and therefore polluting less compared to the old electricity production park composed of more than 90% of conventional thermal power plants generally operating on gas and diesel for isolated regions of the country. Since the promulgation of the 2002 law aimed at the partial opening of the electricity sector to competition and the arrival of new producers, particularly private ones, the electricity production park has been equipped with new efficient power plants, thanks to the massive introduction of the combined cycle from 2008. In addition, this park has been equipped with SPP1 hybrid solar thermal power plants, and wind and photovoltaic farms have been installed in the south of the country. These new technologies are known for their carbon payback time. Indeed, referring to the assessment of the government's actions to mitigate the effects of GHGs in the energy sector, particularly electricity, the data showed that during the period prior to 2016, the total amount of GHG emission reduction reached 17.08 Mt carbon dioxide emissions equivalent, of which 60% (more than 10.28 Mt carbon dioxide emissions equivalent) is attributed to the introduction of the combined cycle (the power plants of Skikda, Terga, and Koudiet Eddraouche). From 2016 to 2020, the total amount of GHG emission reduction recorded was more than 13.57 Mt carbon dioxide emissions equivalent, attributed to efficiency in electricity production thanks to the combined cycle. Furthermore, flared gas emissions have recorded a reduction in emissions of carbon dioxide equivalent to 5.9 Mt (Algeria report, 2023, pp. 89-95). Moreover, when we compare our results to other empirical works that attempted to verify Kuznets' environmental hypothesis for the case of Algeria, we reveal that Algeria has reached, since 2010, the turning point on the environmental Kuznets curve. The results imply that there is improvement in environmental quality in Algeria (Latifa, L., Yang, K., et al., 2014, pp. 1-14; Bouznit, M., and Pablo-Romero, M-D-P., 2016, pp. 93-101; and Younici, K., and Belhadi, Z., 2021, pp. 205-214).

Table (5): Estimate of the long-term relationship

Variables	Coefficient	Standard. Error	t-Statistic	Probability
LOG(CONSOMMELEHABKWH)	-0.147449	0.034323	-4.295936	0.0232
ABONTELMOBILE	0.000000	0.000000	6.323593	0.0080
ABONTELFIXE	-0.000000	0.000000	-3.722630	0.0337
EXPOTIONSERVICETIC	-0.025461	0.009840	-2.587479	0.0813
ABONINTERNETHAUTDEBFIKE	-0.000000	0.000000	4.078925	0.0266
LOG(CATIC)	0.028474	0.028596	0.995713	0.3928
LOG(PIBCAP)	-0.582666	0.454360	-1.282387	0.2898
@TREND	0.017893	0.003998	4.475140	0.0208
$EC = LOG(EMISSCOTMHAB) - 0.1474 * LOG(CONSOMMELEHABKWH) + 0.0000$ $* ABONTELMOBILE - 0.0000 * ABONTELFIXE - 0.0255$ $* EXPOTIONSERVICETIC + 0.0063 IMPOTIONDEBIENTIC + 0.0000$ $* ABONINTERNETHAUTDEBFIKE + 0.0285 * LOG(CATIC) - 0.5827$ $* LOG(PIBCAP) + 9.4043 + 0.0179 * @TREND$				

The source: Established by the authors using Eviews9 software.

The results of estimating the long-term relationship are similar to the results of the short-term. In the long term, the per capita electricity consumption impacts the carbon dioxide emissions. The long-term elasticity coefficient is negative and equal to -0.147. This negative impact is of lesser magnitude in the long term. At the individual level, there is a reduction in the carbon footprint generated by each kilowatt-hour consumed. Furthermore, the growth variables in the number of mobile, fixed internet, and broadband subscribers have had a very small and negligible impact in the long term (marginal effect). The analysis shows that the explanatory power of the model is valid. There is no correlation or homoskedasticity of the errors (probabilities are greater than 5%). The model follows a normal distribution. The probability (Jarque-Bera test) is greater than 5%.

Table (6): Tests of interdependence of errors

<i>Test of Breusch-Godfrey Serial Correlation LM:</i>	<i>Normality test: Jarque-Bera:</i>	<i>Heteroskedasticity test: Breusch-Pagan-Godfrey</i>
<i>F-statistic: 24.40181</i>	<i>Jarque-Bera:1.700</i>	<i>F-statistic:0.39432</i>
<i>Probability: F(2,1): 0.1417</i>	<i>Probability: 0.427</i>	<i>Probability: F(17,3): 0.9088</i>

The source: Established by the authors using Eviews9 software.

The Wald test analysis shows that in the model, the variables taken together impact per capita carbon dioxide emissions with a probability of less than 5%.

Table (7): ARDL Bounds Test and Wald Test

<i>ARDL Bounds Test: Null Hypothesis: No long-run relationships exist.</i>	<i>Wald Test: Equation: Untitled</i>
Test Statistic: 5.273813	Test Statistic Value DF Probability
Critical Value Bounds:	F-Statistic:26132.50 (18, 3) 0.0000
Significance I0 Bound I1 Bound	Chi-square:470385.0 18 0.0000
10% 2.26 3.34	
5% 2.55 3.68	
2.5% 2.82 4.02	
1% 3.15 4.43	

The source: Established by the authors using Eviews9 software.

The Granger causality indicates the presence of a unidirectional relationship between the dependent variable and economic, financial, and ICT indicators. The independent variables impact the environment.

Table (8): Analysis of the causal relationship in the Granger sense

<i>Pairwise Granger Causality Tests: Sample: 2000-2022</i>							
Null Hypothesis:					Obs.	F-Stat	Prob.
LOG(CONSOMMELEHABKWH)	does	not	Granger	cause	22	9.8	0.005
LOG(EMISSCOTMHAB).							
ABONTELEMOBILE	does	not	Granger	cause	22	18.4	0.00
LOG(EMISSCOTMHAB).							
LOG(CATIC) does not Granger cause				LOG(EMISSCOTMHAB).	22	6.5	0.01
LOG(PIBCAP) does not Granger cause				LOG(EMISSCOTMHAB).	22	4.95	0.04

The source: Established by the authors using Eviews9 software.

The CUSUM and CUSUM Squares tests show that the model is stable. The curves are within the margins at the 5% confidence threshold. These results validate the selected ARDL model and the results previously presented (see appendices, figure 1). The Ramsey RESET test (see appendices, table 12) indicated that there is no specification error in the ARDL model (the probability is greater than 5%).

IV-Conclusion:

In this article, we address the effects of digital transformation in Algeria and its implications on the economy and environment. In this context, we evaluate the rebound effect, or the third-order effect, implied by the electricity consumption channel. Thus, we invalidate the rebound effect and conclude that the introduction of clean and intelligent technologies contributed to gains in the economy and energy in Algeria. The third-order effect is validated. The results of the analysis of the rebound effect, whether dissipated or proven, revealed that digital growth indicators have an impact on GHG emissions in the short and long term. Thus, this effect is very negligible. The analysis of the short- and long-term relationship between the level of per capita consumption and

carbon dioxide emissions indicated that electricity consumption has a negative coefficient (or effect), leading to a decrease in the carbon footprint. The inverse relationship is attributed to the introduction of efficient technologies in electricity production activities and to efficiency and climate change mitigation policies implemented since the end of 1999. Indeed, since the early 2000s, Algeria has implemented policies and measures to mitigate the harmful effects of greenhouse gas emissions. The country has committed to all global instruments related to the fight against global warming (UNFCCC, Kyoto Protocol, Paris Agreement, etc.). The government's action plans have focused on programs for the introduction of renewable energy, energy management, and energy efficiency at the sectoral level. The country has set targets to reduce greenhouse gas emissions by 7% and energy consumption by 9% by the year 2030. According to the latest national GHG emissions inventories, the latter (driven upwards by fuel-intensive sectors) have nonetheless recorded a significant reduction, with overall mitigation estimated at 32.1 Mt CO₂ eq until 2020. Emissions avoided in the electricity production activity amounted to a reduction of more than 23.82 Mt CO₂ eq. This reduction in GHG emissions is achieved through the introduction of an installed combined cycle capacity estimated at more than 5149.2 MW from 2002 to 2020.

Furthermore, the Granger causality test indicates unidirectional causality. The economic and digital growths have impacted the environment. These results confirm the theses of Hilty, L.-M., Arnfalk, P., et al. (2006) and Tsaurai, K. and Chimbo, B. (2019). The economic and digital growth indicators are channels that improve environmental sustainability and generate a reduction in carbon dioxide emissions through the transition of the products to virtual services or through the use of efficient technologies that are less energy-intensive in terms of consumption of energy and materials.

- Appendices:

Table (9): Evolution and distribution of online payment transactions

	2017	2018	2019	2020	2021	2022
Telecom	87 286	138495	141552	4210284	6993135	7490626
Transportation	5677	871	6292	11350	72164	195490
Insurance	2467	6439	8342	4845	8372	23571
Electricity/water	12414	29722	38806	85676	120841	302273
Administrative services	0	1455	2432	68395	155640	153957
Sale of goods/services	0	0	5056	213410	471194	882208
Provider service						
Total number of transactions	107844	176982	202480	4593960	7821346	9048125
Total amount of transactions: A Million DA	267993	332592	503870	5423727	1117647	18151104

The source: Established by the authors from data extracted from www.giemonetique.dz

Table (10): Stationarity tests

Variables	Type	Stationarity	Integration order
ABONINTERNETHAUTDEBFIXE	Constant and trend	1 st difference	I(1): Prob. = 0.0292
ABONTELFIXE	Without constant and trend	1 st difference	I(1): Prob. = 0.0025
ABONTELMOBILE	With constant	1 st difference	I(1): Prob. = 0.0204
CATIC	With constant	1 st difference	I(1): Prob. = 0.0005
PIBCAP	With constant	At level	I(0): Prob. = 0.04
EMISSCOTMHAB	Constant and trend	At level	I(0): Prob. = 0.05
CONSOMMELEHABKWH	Constant and trend	1 st difference	I(1): Prob. = 0.0013

EXPOTIONSERVICETIC	Without constant and trend	1 st difference	I(1): Prob. = 0.0025
IMPOTIONDEBIENTIC	Without constant and trend	1 st difference	I(1): Prob. = 0.001

The source: Established by the authors using Eviews9 software.

Table (11): Results of estimation of the ARDL (2, 1, 1, 0, 1, 1, 0, 1, 1)

<i>Dependent Variable: LOG(EMISSCOTMHAB)</i>				
Variables	Coefficient	Standard Error	t-Statistic	Probability
LOG(EMISSCOTMHAB(-1))	-1.215702	0.207913	-5.847178	0.0100
LOG(EMISSCOTMHAB(-2))	-0.573983	0.113414	-5.060953	0.0149
LOG(CONSOMMELEHABKWH)	-0.276060	0.071779	-3.845996	0.0310
LOG(CONSOMMELEHABKWH(1))	-0.135277	0.084242	-1.605811	0.2067
ABONTELMOBILE	5.40E-09	1.94E-09	2.788922	0.0685
ABONTELMOBILE(-1)	1.46E-08	3.08E-09	4.748923	0.0177
ABONTELFIXE	-5.43E-08	1.79E-08	-3.040779	0.0558
EXPOTIONSERVICETIC(-1)	-0.088544	0.019249	-4.599825	0.0193
IMPOTIONDEBIENTIC	-0.028046	0.011709	-2.395236	0.0963
IMPOTIONDEBIENTIC(-1)	0.045518	0.010706	4.251498	0.0238
ABONINTERNETHAUTDEBFIKE	9.22E-08	2.63E-08	3.510345	0.0392
LOG(PIBCAP)	1.100539	0.608361	1.809022	0.1682
LOG(PIBCAP(-1))	-2.725994	0.867185	-3.143500	0.0515
LOG(CATIC)	0.115476	0.057136	2.021077	0.1365
LOG(CATIC(-1))	-0.036044	0.043846	-0.822047	0.4713
C	26.23516	15.80941	1.659464	0.1956
@TREND	0.049916	0.010804	4.620166	0.0191
R-squared: 0.999345	Mean dependent var.: 1.234910			
Adjusted R-squared: 0.995630	S.D. dependent var.: 0.125432			
F-statistic: 269.0495	Durbin-Watson:2.692	Probability	(F-statistic):	
		0.000325		

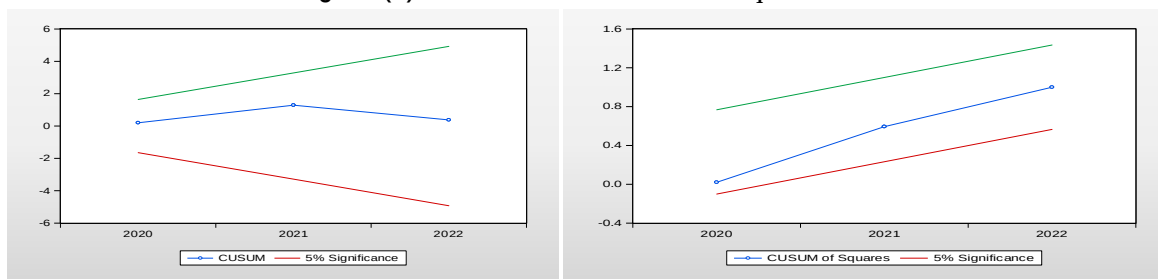
The source: Established by the authors using Eviews9 software.

Table (12): *Stability test*

Test of Ramsey RESET Test	Value	df	Probability
<i>T-statistic</i>	0.596245	2	0.6115
<i>T-statistic</i>	0.355508	(1, 2)	0.6115

The source: Established by the authors using Eviews9 software.

Figure (1): CUSUM and CUSUM Squares tests



The source: Established by the authors using Eviews9 software. Tests obtained by simulating the ARDL equation in the MCO model.

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