

The role of ICT in MENA environmental sustainability: A panel GMM approach

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Abstract

Climate change poses a major threat to environmental sustainability worldwide, particularly in the Middle East and North Africa (MENA) region, which faces rising temperatures, prolonged droughts, and air pollution. The role of Information and Communication Technology (ICT) in environmental sustainability remains debated, as studies report both positive and negative effects. This study investigates the impact of ICT, education, GDP per capita, and tourism on environmental sustainability in selected MENA countries from 2015 to 2020. Annual data were obtained from the World Development Indicators, and the Arellano-Bond Generalized Method of Moments (GMM) model was employed for analysis. The findings indicate that ICT contributes positively to environmental sustainability in the sampled countries, while GDP per capita has a detrimental environmental effect. These results suggest that policymakers should expand access to ICT and promote its integration into energy consumption systems and sustainable economic activities to support environmental sustainability in the region.

Keywords: MENA, Panel GMM, Information and Communication Technology (ICT), CO² emission, education

Peran TIK dalam keberlanjutan lingkungan di MENA: Pendekatan GMM panel

Abstrak

Perubahan iklim merupakan ancaman besar terhadap keberlanjutan lingkungan di seluruh dunia, khususnya di kawasan Timur Tengah dan Afrika Utara (MENA), yang menghadapi peningkatan suhu, kekeringan berkepanjangan, dan pencemaran udara. Peran Teknologi Informasi dan Komunikasi (TIK) dalam keberlanjutan lingkungan masih menjadi perdebatan karena berbagai penelitian menunjukkan dampak positif maupun negatif. Studi ini menganalisis pengaruh TIK, pendidikan, PDB per kapita, dan pariwisata terhadap keberlanjutan lingkungan di beberapa negara MENA selama periode 2015–2020. Data tahunan diperoleh dari World Development Indicators, dan analisis dilakukan menggunakan model Generalized Method of Moments (GMM) Arellano-Bond. Hasil penelitian menunjukkan bahwa TIK berkontribusi positif terhadap keberlanjutan lingkungan di negara-negara sampel, sementara PDB per kapita memberikan dampak yang merugikan terhadap lingkungan. Temuan ini mengindikasikan bahwa pengambil kebijakan perlu memperluas akses terhadap TIK dan mendorong integrasinya dalam sistem konsumsi energi serta kegiatan ekonomi berkelanjutan guna mendukung keberlanjutan lingkungan di kawasan tersebut.

Kata kunci: Timur Tengah dan Afrika Utara, Panel GMM, Teknologi Informasi dan Komunikasi (TIK), Emisi CO₂, Pendidikan

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INTRODUCTION

The information and knowledge economy is evolving rapidly due to the rapid development of information and communication technologies (ICTs), presenting new opportunities and challenges for businesses, governments, and individuals alike. Traditional ways of activities are being altered by new technologies and uses of current ICTs, and ICTs are becoming an essential part of the economic and social fabric (van Ark et al., 2011); (Setyadharma & Fadhilah, 2021) The way people live, work, and communicate has changed in ways never seen before due to the continuous digital transformation, which is defined by the widespread use of information technology across sectors and society. However, integrating mobility and activity patterns has advantages and disadvantages, including the need to strike a balance between efficiency and sustainability, address the digital divide, and ensure security and transparency (Pawlak et al., 2020).

The dynamic nature of digital technology, regarded as the new wave in 21st-century societies, has brought benefits in improved efficiency and innovation, as well as emerging problems such as elevated CO₂ emissions. Global environmental degradation and climate change issues occur not only in developing countries but also in their more developed counterparts, mainly due to carbon dioxide emissions (Houghton, 2010). To address the worsening environmental situation, the concept of environmental sustainability was introduced, highlighting the relationship between humans and the environment. The burden of population growth has led to emerging challenges in housing, energy, food, and industry, all of which contribute to environmental degradation, underscoring the pressing need for a more sustainable approach.

The MENA region is highly vulnerable to the threat of climate change (Waha et al., 2017). The ever-higher temperatures, increased risk of drought and desertification, pollution, and loss of biodiversity are among the adverse impacts of environmental imbalance. Information and communication technology (ICT) and education are crucial for resolving these problems. ICT may help lessen the impact of climate change and other environmental concerns through transformative, innovative solutions, while education can increase students' understanding of climate change and their motivation to take action (Mochizuki & Bryan, 2015; Li, 2018). It has been demonstrated that globalization and ICT may reduce CO₂ emissions in the Latin American and Caribbean region, demonstrating their capacity to stop environmental degradation (Ahmed et al., 2021).

ICT affects the environment in various ways, both positively and negatively. Positively, it can lower CO₂ emissions and increase energy efficiency. On the other hand, the use and production of ICT devices can exacerbate environmental deterioration (Houghton, 2010). The control of these direct consequences is made more difficult by the proliferation of gadgets and the energy-intensive manufacturing process. The replacement of tangible commodities with information goods and the shift from distant communication to travel are examples of indirect consequences (Berkhout & Hertin, 2004). ICT has significant potential to aid both adaptation and mitigation of climate change, despite these difficulties (Houghton, 2010).

There are several reasons to reconsider whether ICT can support environmental sustainability in MENA nations. There has been an increase in energy consumption due to the construction of strong telecommunications infrastructure, particularly broad mobile networks and high-speed internet connections, which have been major investments for many countries in the MENA region. Studies conducted by Berkhout & Hertin (2004) have shown that the production of ICT infrastructure harms the environment and human health. The region's contribution to global Greenhouse Gas (GHG) emissions is considerably lower than that of other regions. However, its annual per capita emissions are among the highest in the world, and its ranking is similar to that of industrialized countries such as Japan, Australia, and New Zealand. Another reason is that the governments of the Middle East and North Africa (MENA) have acknowledged the role of ICT in economic growth and have put in place policies and plans to support the industry. With the growing trend of ICT integration into human activities, the government needs to ensure that the benefits of ICT adoption offset the environmental impacts.

Numerous studies have found that the development and adoption of ICT have driven GDP growth by improving market efficiency, reducing price volatility, and boosting employment (Haftu, 2019; Kallal et al., 2021; Moore et al., 2021; Nguyen et al., 2021). The intensity of economic activity often leads to environmental degradation as reflected in the first phase of EKC (Mahmood et al., 2023); (Rofiuddin et al., 2019). The impact of ICT on economic growth is only one aspect of many facets (Nugraha, 2023). The production and distribution of ICT infrastructure increase energy use and negatively impact the environment (Benghalem et al., 2021). Another issue is the waste generated by these ICT products, which contain harmful substances and threaten the ecological balance (Salahuddin et al., 2016). On the other hand, the emergence of ICT has led the better-informed consumer to use eco-friendly products and increase energy efficiency by substituting traveling with online versions of many activities. By replacing conventional products and services with virtual ones, the substitution effect reduces energy consumption and CO₂ emissions.

The link between ICT, economic growth, and environmental sustainability is unclear, given both the positive and negative environmental effects; the topic remains highly debated among scholars. Hence, the study aims to explore the impact of ICT, economic growth, education, and tourism on environmental sustainability in the MENA region. Some MENA nations rely on tourism as an economic driver, and tourism activities may contribute to environmental deterioration through increased CO₂ emissions (Benghalem et al., 2020). Other studies have produced conflicting findings on the effects of tourist arrivals and tourism investment on environmental sustainability (Lee, 2002). This study contributes to the literature by examining the impact of ICT, economic growth, education, and tourism on environmental sustainability in the MENA region. To the author's knowledge, no studies have been conducted in the MENA region linking ICT and education to environmental sustainability. The region is interesting to explore due to its high GHG emissions per capita, while at the same time having significant potential to develop green energy by harnessing abundant renewable sources such as wind and solar, and strong ICT

growth. Lastly, we employ panel GMM Arellano-Bond that accounts for serial correlation and endogeneity.

The rest of this study is structured as follows: Section 2 provides an overview of the pertinent literature on the linkage between ICT and environmental sustainability. The data and the research methodology are described in Section 3. The results are presented and discussed in Section 4, and Section 5 offers suggestions and conclusions.

The evidence of ICT's effect on CO₂ emissions is not entirely consistent. A study by Chen (2020) shows a strong negative effect, underscoring the potential for economic growth and emissions reduction in emerging nations. On the other hand, Gelenbe (2015) offers a more circumspect perspective: the study argues that careful consideration must be given to how various ICT sectors affect energy use and emissions, whereas Salahuddin's research in EU nations shows a correlation between Internet use and CO₂ emissions that may pose a threat to sustainable development.

To foster the growth of a country's tourism sector, effective and appealing promotion is essential. Diverse experiences, including stunning tourist destinations, preserved cultural heritage, and distinctive traditional architecture, are among the offerings for visitors (Hayat et al., 2020). The growth of tourism increases national carbon emissions, and the current pro-growth strategies adopted by many destinations conflict with zero-carbon objectives. The policy implications of tourism development on national carbon emission trajectories are significant. If tourism can simultaneously lower carbon emissions and boost GDP growth, it becomes a sensible decision to expand this sector.

A large number of studies have consistently found a positive impact of education on environmental sustainability (Koziuk, 2019; Mbokazi, 2021; Salahuddin et al., 2016), especially in developing nations. While a few studies reported contrasting results (Mayer, 2013; Kinda, 2010; Caird, 2015), others offered a more nuanced view, considering the roles of development and teaching models.

Numerous studies have shown that GDP growth and CO₂ emissions have both direct and indirect impacts. Begum et al. (2015) found a positive relationship between GDP per capita and CO₂ emissions, noting a notable rise in emissions in Malaysia as GDP per capita increased.

METHOD

The data source for this research uses secondary data taken from the World Development Indicators (WDI) website. The data used in this research is panel data on eight Middle East and North African (MENA) countries, including Bahrain, Egypt, Jordan, Kuwait, Morocco, Qatar, the United Arab Emirates, and Oman, for the period 2015 to 2020. The dependent variable is environmental sustainability proxied by carbon dioxide (CO₂) emissions per capita, while the independent variables are per capita income, secondary schooling enrollment, ICT proxied by the number of internet users, and international tourist arrivals.

The data analysis used is GMM panel data analysis processed with STATA. Arellano and Bond estimated the parameters of a dynamic panel data model known as the Arellano-Bond GMM using GMM principles. A model that establishes a correlation between error

and the explanatory endogenous variable is the dynamic panel data model. The dynamic panel data model is biased and inconsistent when estimated by OLS. Therefore, the Arellano-Bond GMM estimation method is used in this work to obtain efficient, unbiased, and consistent estimates. Dynamic panel data analysis is used to determine which independent variables influence the dependent variable, namely Carbon Dioxide Emissions (CO₂) as an indicator of short- and long-term carbon dioxide emissions. Dynamic panel data regression is a regression method that adds the lagged dependent variable as an independent variable. The following will outline the procedures for calculating the Arellano-Bond GMM parameters.

The dynamic model equation is defined as follows:

$$y_{it} = \alpha + \gamma y_{it-1} + X_{it}\beta + u_{it} \quad (1)$$

Where:

- y_{it} = observations on the independent variable of individual i at period t
- α = intercept
- γ = lag coefficient of the dependent variable
- y_{it-1} = Observations on the i -th individual dependent variable at $(t - 1)$
- X_{it} = The observation matrix on independent variables is $1 \times k$
- β = vector coefficients of independent variables of size $k \times 1$
- u_{it} = panel regression error for the i -th cross-section unit in the t -th period

Parameter estimation in the dynamic model uses the First Difference Generalized Method of Moments (FDGMM), which produces consistent, valid, and unbiased estimates. Consistency testing uses the Arellano-Bond Test, and instrument validity testing uses the Sargan Test. Meanwhile, the model is said to be unbiased if the lag parameter value of the dependent variable obtained using FDGMM parameter estimation lies between those obtained using pool least squares estimation and the fixed-effect model.

In the dynamic panel data model, short-term effects can be seen from the coefficient vector of independent variables (β). The long-term effect of the dependent variable is calculated using the following formula:

$$CLR_j = \frac{B_j}{1-\gamma} \text{ with } j = 1, 2, \dots, k \quad (2)$$

Where:

- CLR_j = Long-term coefficient of independent variable j
- B_j = Coefficient of j independent variable
- γ = The lag coefficient of the dependent variable

FINDING AND DISCUSSION

A summary of the distribution and behavior of the study sample data is obtained using descriptive statistics, which examine the minimum, maximum, mean, and standard deviation for each independent and dependent variable, as reported in Table 1. The variable CO₂ counts for the CO₂ emission metric ton per capita, GDP counts for per capita income

in current USD, SS counts for the secondary school enrollment as % of gross school enrollment, ICT counts for the number of people using the internet as a percentage of the population, and INTOUR counts for the number of international tourist arrivals.

Table 1. *Descriptive Statistics*

Variable	Mean	Std. Dev	Min	Max
CO2	14,9456	10,9540	1,72	35,29
SS	20,0208	12,0891	1	38
INTOUR	2,93070	0,8864	0	3,871
ICT	4,36696	0,2675	3,6328	4,6051
GDPc	9,53546	1,1210	8,0331	11,1122

Table 2. *Correlation Matrix*

Variable	CO2	GDPc	SS	ICT	INTOUR
CO2	1,0000				
GDPc	0,9751	1,0000			
SS	-0,1627	-0,1633	1,0000		
ICT	0,7905	0,8132	-0,0603	1,0000	
INTOUR	0,2007	0,2309	0,1328	0,0414	1,0000

The evidence shows an average carbon emission (CO2) per capita of 14,9, with a standard deviation of 10,9. This figure shows that the sampled MENA countries have an average CO2 emission of nearly 15 tons per capita and an average internet user rate of 4,4% of the total population. At the same time, secondary school enrollment accounts for an average of 20,02% of total school enrollment.

Dynamic Panel Data Analysis

Specification testing of the dynamic panel model was carried out using the FDGMM Arellano-Bond estimator, focusing on unbiasedness, instrument validity, and consistency. Based on Table 3, the CO2 lag variable coefficient is 0.255 (CO2 lag coefficient < 1) and lies between the values of 0.253 and 0.935. The value of 0.253 is the result of estimation using the dynamic fixed effect model (FEM), while the value of 0.935 is the result of dynamic pool least squares (PLS) estimation. This result shows that the FDGMM Arellano-Bond estimation model is not biased.

Table 3. *Specification Testing*

Criteria	Critical Value	P-Value
Coefficient Lag of Dynamic FEM	0,253	0,045
Coefficient Lag of FDGMM	0,255	0,000

Coefficient Lag of PLS Model	0,935	0,000
Sargan Test	12,191	0,202
Arellano-Bond (m ₁) Test	-1,513	0,130
Arellano-Bond (m ₂) Test	-1,209	0,227

Model specification testing uses the Sargan Test to check the validity of the variable instruments used in this study. The Sargan Test results in Table 3 show a p-value of 0.202, which is greater than 0.05. This result means that there is no correlation between residuals and over-identifying restrictions or instrument variables that are used more than the estimated number of parameters. Therefore, the instrument variables used are valid. The final Specification Test assesses the model's consistency using the Arellano-Bond Test. The results of the Arellano-Bond Test (m2) in Table 3 show a p-value of 0.227 > 0.05. It means that the dynamic panel method with FDGMM Arellano-Bond estimation has met the best model criteria.

The dynamic panel data model is used to determine the independent variables that influence the dependent variable (CO2) both in the long and short term. The empirical model in this study is as follows:

$$\widehat{Co2}_{it} = -9,536 + 0,255Co2_{t-1} + 0,038Edu_{it} - 1,861ICT_{it} - 0,122Tour_{it} + 2,957GDPC_{it}$$

Table 4. *The Significance of Variables and Long-Term Elasticity*

Predictor	Shor run		Long run	
	Coefficient	P-Value	Coefficient	P-Value
EDU	0,038	0,122	0,514	0,111
ICT	-1,86	0,071***	-2,496	0,056***
TOUR	-1,22	0,137	-0,164	0,104
GDPC	2,957	0,064***	3,967	0,090***

***denotes level of significance at 1%

Table 4 shows the result from equation 3 using Arellano-Bond dynamic panel estimation. There is a positive relationship between CO2 emissions and their lagged values; the value $\delta = 0.255$ indicates that if CO2 emissions increased by 1 metric ton per capita in the previous period, they would increase by 0.255 metric ton per capita in the current period.

In both the short and long run, the ICT proxy, measured by the number of internet users, shows a negative and significant impact on CO2 emissions per capita at the 1% significance level.

However, the long-run coefficient has a larger magnitude, at -2,5, compared to -1,86 in the short run. The figure shows that if the number of internet users increases by 1%, CO2 emissions per capita will decrease by 2,5 metric tons in the long run and by 1,86 metric tons in the short run. The income per capita variable also shows a significant, positive impact on CO2 emissions per capita in selected MENA countries, with a stronger effect in the long

run, as shown by the coefficient values of 3,97 and 2,95 in the short run. The remaining variables indicate that neither secondary school enrollment nor international tourist arrivals has a significant impact on CO₂ emissions in the short- or long-run.

Discussions

In both the short and long run, the findings show that the number of internet users, as a proxy for ICT, has a significant and negative impact on CO₂ emissions. These findings indicate that environmental sustainability can be promoted through internet use in selected MENA countries and confirm previous studies that find that ICT has a favorable impact on the environment. Zhang & Liu (2015) found in their study on the impact of the ICT industry on CO₂ emissions in China that ICT promotes reduced CO₂ emissions. Similarly, a study by Asongu et al. (2017) suggests that ICT is beneficial in mitigating the effects of globalization on the environment, proxied by CO₂ emissions, in Sub-Saharan African (SSA) Countries. Our findings are also consistent with the results of studies by Kahia et al. (2019), Khan et al. (2020), Ahmed et al. (2021), and Ahmed & Le (2021). The channels through which ICT promotes environmental sustainability in the MENA region are by providing better quality and wider coverage internet service, providing the people in the region with smart technologies with improved efficiency in transportation by utilizing smart transport systems, energy use by developing green and sustainable energy, and also the education system, environmental monitoring, as well as manufacturing processes which lower CO₂ emissions and improve environmental sustainability. On the other hand, the findings are in contrast with studies of Salahuddin et al. (2016), which found that internet use is raising the threat to sustainable development in EU countries, and Avom et al. (2020), who explored the relationship between ICT as proxied by internet penetration and CO₂ emission in SSA countries, found that ICT worsens environmental quality.

The empirical results indicate that GDPC has a significant and positive impact on environmental sustainability, as measured by CO₂ emissions, suggesting that higher per capita income is associated with higher CO₂ emissions and worsens environmental quality. As countries in the MENA region experience rapid economic growth and become more globally integrated, energy consumption has risen to unprecedented levels, leading to elevated CO₂ and other GHG emissions. In some of these countries, carbon dioxide emissions exceed the global average. The MENA region hosts countries with the world's highest fossil fuel reserves, resulting in low gas prices. However, younger generation consumers are increasingly demanding environmentally friendly products and sustainable business practices, including advocating for the development of renewable energy and green ICTs. This finding aligns with previous studies by Maalej & Cabagnols (2020), which suggest that countries tend to emit more CO₂ as they pursue development. Begum et al. (2015) and Perwithosuci et al. (2023) also found a similar impact of GDP and oil consumption on carbon dioxide emissions in Malaysia and Indonesia, respectively. However, the conclusion is in contrast with the research of Aye & Edoja (2017), whose research on 31 developing countries found that economic growth negatively affects CO₂ emission in the low growth regime, and Yang et al. (2022), who confirmed the inverted U

shape of the environmental Kuznets curve between economic growth and carbon emission in China.

CONCLUSION

Numerous studies have explored the relationship between ICT and environmental sustainability across different parts of the globe, with scholars divided in their opinions. This study aims to investigate an issue specific to the MENA region, given its economic importance and vulnerability to environmental degradation and climate change. We use the Arellano-Bond panel approach over the 2015 to 2020 period. The results suggest that ICT has a significant, negative impact on environmental sustainability, as measured by CO₂ emissions, in the short and long run, while GDP per capita has a positive, significant effect on the environment. The remaining variables for education and tourist arrivals do not have a significant impact on the dependent variable. This study contributes to the existing literature on the dynamic between ICT and the environment in the MENA region, one of the regions with the highest GHG emissions and facing the adverse impacts of climate change.

The findings from our study have several important points for policymakers. Given the significant impact of ICT on environmental sustainability, the government needs to collaborate with the private sector and society to expand the reach of high-quality internet networks. Start promoting green ICT and renewable energy development that are more environmentally friendly to maintain sustainable development. Policymakers need to adopt sustainable practices in line with the green GDP concept (Hidayah et al., 2023) to ensure that high economic growth does not harm the environment. Increase investments in the development of smart cities and remote sensing technology for environmental monitoring, and in the use of digital applications for businesses and government activities to reduce paper use and business travel, thereby reducing CO₂ emissions.

Limitations of this research include a small sample due to data availability constraints and the failure to explore the impact across various sectors of the economy. The study was conducted using data from selected MENA countries; the findings cannot be generalized to other regions. Future research can fill the research gap by classifying countries within a region by sector or level of national income.

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