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ICT AS A DRIVER OF GREEN ECONOMIC GROWTH IN THE MENA AREA

Anna M. Ferragina, *Stefano Iandolo*, *Ivan Sergio* and *Erol Taymaz*

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SHIFTING PARADIGMS:
Opportunities for a Deeper EU-Mediterranean Integration in a Changing World
ICT AS A DRIVER OF GREEN ECONOMIC GROWTH IN THE MENA AREA

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ICT AS A DRIVER OF GREEN ECONOMIC GROWTH IN THE MENA AREA

CONTENTS

ABSTRACT

This study investigates the relationship between Information and Communication Technologies (ICTs) and environmental sustainability in the Middle East and North Africa (MENA) region. Through the analysis encompassing various dimensions of ICT adoption and energy utilization, our findings offer crucial insights into the potential impact of technological advancements on carbon emissions and energy conservation. The results reveal peculiar patterns, emphasizing the pivotal role of ICTs in increasing energy efficiency, and mitigating environmental impact. Alternative energy sources show promise for emissions reduction, highlighting the importance of sustainable energy technologies. Furthermore, the multifaceted nature of these relationships underscores the need for context-specific policies and interventions. This research provides a foundation for further exploration and policy formulation towards a sustainable and technologically driven future for the MENA region.

RÉSUMÉ

Cette étude examine la relation entre les technologies de l'information et de la communication (TIC) et la durabilité environnementale dans la région du Moyen-Orient et de l'Afrique du Nord (MENA). En analysant les différentes dimensions de l'adoption des TIC et de l'utilisation de l'énergie, nos résultats montrent l'impact potentiel des avancées technologiques sur les émissions de carbone et la conservation de l'énergie. Les résultats révèlent des tendances particulières, soulignant le rôle central des TIC dans l'augmentation de l'efficacité énergétique et l'atténuation de l'impact environnemental. Les sources d'énergie alternatives sont prometteuses en matière de réduction des émissions, soulignant l'importance des technologies énergétiques durables. En outre, la nature multiforme de ces relations souligne la nécessité de politiques et d'interventions adaptées au contexte. Cette recherche fournit une base pour une exploration plus approfondie et la formulation de politiques visant un avenir durable et technologique pour la région MENA.

ملخص

تكنولوجيا المعلومات والاتصالات كمحرك للنمو الاقتصادي الأخضر في منطقة الشرق الأوسط وشمال أفريقيا

تتناول هذه الدراسة العلاقة بين تكنولوجيا المعلومات والاتصالات والاستدامة البيئية في منطقة الشرق الأوسط وشمال أفريقيا. ومن خلال التحليل الذي يشمل أبعاداً مختلفة لاعتماد تكنولوجيا المعلومات والاتصالات واستخدام

الطاقة، تقدّم النتائج التي توصلنا إليها رؤى مهمة حول التأثير المحتمل للتطورات التكنولوجية على انبعاثات الكربون والحفاظ على الطاقة. وتكشف النتائج عن أنماط مميزة تؤكد على الدور المحوري لتكنولوجيا المعلومات والاتصالات في زيادة كفاءة استخدام الطاقة، والتخفيف من الأثر البيئي. تظهر مصادر الطاقة البديلة نتائج واعدة لخفض الانبعاثات، مما يسلط الضوء على أهمية تكنولوجيات الطاقة المستدامة. وعلاوة على ذلك، تؤكد الطبيعة المتعددة الأوجه لهذه العلاقات على الحاجة إلى سياسات وتدخلات محددة السياق. ويوفر هذا البحث ركيزة أساسية لمزيد من الاستكشاف وصياغة السياسات من أجل مستقبل مستدام وقائم على التكنولوجيا في منطقة الشرق الأوسط وشمال أفريقيا.

INTRODUCTION

The traditional focus of economists on GDP growth and productivity as the sole indicators of economic success has been challenged. The negative environmental consequences of unchecked economic growth have become increasingly apparent, leading economists to adopt a more holistic view of economic success that includes environmental sustainability. Concepts such as 'green productivity', 'green growth' and the 'circular economy' have emerged, incorporating environmental considerations into traditional productivity and growth models. Furthermore, some economists argue that prioritizing sustainable economic growth can foster a more inclusive and equitable society (Kahn, 2015). However, this area of research remains relatively under-researched, with numerous perspectives and opinions on the trade-offs between economic growth, productivity and environmental sustainability still being debated.

The increasing severity of pollution and the criticism of an unsustainable production method characterized by a "pollute first, treat later" approach (Zhao et al., 2021; Wang et al., 2020) cannot be ignored. A significant proportion of the urban global population is exposed to elevated levels of fine particulate matter (PM 2.5), with 96% exceeding the latest WHO health-based guidelines (World Health Organization, 2021). Environmental concerns go beyond the economic and social impact to include potential effects on the climate, oceans, fauna, and flora. Scientists worldwide are warning of the imminent threat of mass extinction (Barnosky et al., 2011).

The MENA region plays a pivotal role in the global energy landscape, holding a significant share of the world's energy resources. As of 2021, it accounted for 52% of the world's oil reserves and 43% of its natural gas reserves (BP, 2022). However, air quality in the Middle East and North Africa (MENA) region has deteriorated significantly, with Egypt being the worst country for PM2.5 exposure and in Cairo the PM2.5 concentration being about 12 times as high as the WHO limit (Wolf at al., 2022). Other major cities in the region also face similar air quality issues. The shift in energy production and consumption patterns has contributed to high levels of air pollution. Most cities in low- and middle-income countries in MENA fail to meet air quality guidelines set by the World Health Organization (WHO). Airborne particulate matter (PM) resulting from emissions by power plants, factories, and vehicles is a major concern. The consequences of poor air quality go beyond financial costs and have a significant impact on human health. An estimated 125,000 lives were lost in the MENA countries in 2013 to diseases associated with outdoor and household air pollution (e.g., WB and IHME, 2016). These health issues not only cause suffering but also impede economic development. Egypt and Lebanon are among the countries most affected, experiencing high numbers of deaths and substantial economic losses. Overall, the MENA region faces severe air quality challenges, with significant implications for public health and the economy, and urgent measures are necessary to address these issues and improve air quality for the well-being of the population and sustainable development. Urbanization has been a leading factor contributing to increased pollution in the region as most of the population in countries like Bahrain, Jordan, Kuwait, Lebanon, Qatar, Saudi Arabia, and the United Arab Emirates live in urban areas.

Urbanization has, indeed, led to a substantial increase in energy demand and related emissions, further deteriorating air quality in major MENA cities. In summary, tackling air pollution and improving air quality in the MENA region is crucial to protect public health, promote sustainable development, and mitigate the negative impacts of urbanization and energy consumption.

In addition, air pollution-induced rising temperatures exacerbate the issue of water scarcity, which is a pressing concern in the MENA region. Increased temperatures have two significant impacts on water availability. Firstly, they accelerate water evaporation, leading to reduced water resources. Secondly, higher temperatures contribute to increased sedimentation, including mould, which further affects water quality. Moreover, water supplies are often damaged by poor management, pollution, and over-consumption, in addition to supply-side reductions due to climate change impacts and the ecosystem degradation mentioned above. On the other hand, many scholars (Femia F. & Werrek C., 2021) argue that the limited availability of water in the region could potentially lead to conflicts as various actors compete to secure their share of the scarce resources.

Following the literature, we know that ICT technology has the potential to contribute significantly to sustainable low-carbon development (Dong et al., 2021; Wang et al., 2021) and play a relevant role in addressing climate change (Lahouel et al., 2021). However, the diffusion of ICT faces barriers in rural or less developed regions, including technical requirements (Lee et al., 2017) and educational disparities (Fong, 2009), resulting in a concentration mainly in developed areas, which is associated with economic growth and environmental impacts (Liu et al., 2021). Hence, ICT technology can lead to an unbalanced regional industrial structure, resulting in wasted resources and increased emissions (Fang et al., 2020; Li et al., 2017). In addition, the attractiveness of areas with high levels of ICT technology contributes to additional energy consumption and subsequent emissions (Wu et al., 2021). Nevertheless, ICT technology exhibits characteristics of industrial convergence and knowledge spillovers, which promote technological progress and low-carbon development across the industries (Moyer & Hughes, 2012). The impact of ICT technology on carbon emissions remains mixed and poses challenges for policymakers. While numerous studies have examined the impact of industrial agglomeration on carbon emissions, few have specifically analysed the impact of ICT agglomeration. Despite the potential for the ICT industry to reduce emissions (Haini, 2021; Lu, 2018), the direct impact of ICT agglomeration on emissions reduction may be limited. However, it can promote green productivity through its ability to facilitate knowledge transfer between different technologies.

The Arab Development Summit Youth Forum, which took place in Sharm-el-Sheikh, Egypt in January 2011 had as main objective facilitating dialogue between young Arab leaders and ICT entrepreneurs, allowing them to engage with Arab decision-makers and provide recommendations on empowering youth in the MENA region through ICT. The events surrounding Tunisia's Jasmine Revolution and its aftermath underscored the youth's desire for good governance. The demands expressed by youth-led Arab movements for change emphasized the importance of access to information, freedom of expression, and enhanced economic opportunities. These priorities gained even greater significance when Egypt itself experienced a widespread uprising just one week after the Youth Forum. The key messages from the Forum evaluate the social and economic opportunities that ICT presents to the youth in the MENA region.

This study aims to fill a gap in the existing literature by providing new insights into the potential relationship between ICT technology and CO2 intensity for MENA countries. ICT technology can promote economic prosperity without compromising environmental integrity: companies operating in the ICT sector have the potential to drive green productivity growth by implementing innovative solutions for energy and resource management. In addition, ICT agglomeration can facilitate the diffusion of knowledge and skills related to environmental sustainability, foster synergies between different economic activities and create new business opportunities aligned with environmental sustainability goals. Furthermore, ICT technology can play an important role in creating green jobs and facilitating the training of a workforce specialized in environmental sustainability, thereby facilitating the transition to a more sustainable and resilient economy.

Based on the premises outlined so far, in this work, we aim to empirically investigate three distinct hypotheses pertaining to the effects of ICT adoption on energy dynamics and on emissions. Specifically, we hypothesize that ICT exerts three key influences: 1) the conservation of energy, 2) the optimization of energy utilization, and 3) the reduction of pollutant emissions. Assuming these hypotheses hold true, and aligning with this conceptual framework, we posit that increasing the penetration/usage of ICT can enhance the energy efficiency of production processes, leading to both energy conservation and the enabling of the adoption of cleaner alternative energy sources, thereby reducing CO2 emissions.

The study suggests that the ICT technology, acting as a knowledge driver and influencing the innovative performance of European regions, should enhance the region's capacity to adopt cleaner technologies, thereby reducing the negative environmental impacts associated with growth. The results show that the ICT technology serves as a critical indicator of a region's ability to increase green productivity. However, the relationship is complex and can be non-monotonic, as the economies of scale resulting from ICT technology can have a negative impact on CO2 intensity. Further analysis shows that the observed improvement in green CO2 intensity is mainly due to efficiency changes in green productivity, suggesting technological advances that promote coordinated economic growth, energy savings and emission reductions. In addition, the results show that CO2 intensity is influenced by proximity to regions with high levels of green productivity, highlighting the importance of promoting ICT agglomeration as a means of fostering sustainable and green economic growth within regions.

The paper is organized as follows. In Section 2, we review the related literature to which this paper aims to contribute to, and we outline our research hypothesis. Section 3 describes the hypotheses and the estimation strategy. In Section 4, we introduce our data sources. In Section 5 we show some stylised facts, while in Section 6 we discuss our results. Section 7 concludes the paper.

ICT AND ENVIRONMENT: A BRIEF LITERATURE REVIEW

ICT tools have become essential in today's business and social environments (Cardona et al., 2013; Dogan & Aslan, 2017). The significant decrease in the cost of ICT has facilitated significant investment in ICT, leading to economic restructuring and integration into our daily lives (Cardona et al., 2013). ICT plays an important role in various aspects such as economic growth, education, foreign direct investment, financial development, trade, good governance, and energy consumption (Appiah-Otoo et al., 2022; Appiah-Otoo & Song, 2021). As a result, the environmental impacts of ICTs have received increasing attention from scholars and policy makers.

Scholars have presented different perspectives on the environmental impact of ICTs. Some argue that ICTs contribute to improving environmental quality, as evidenced by a negative correlation between ICTs and carbon dioxide emissions (CO2E) in 13 G-20 countries (Ahmed et al., 2021; Lee et al., 2022; Nguyen et al., 2020). However, other studies suggest that ICTs have a negative impact on the environment (Salahuddin et al., 2016). For example, Yang et al. (2016) found a positive correlation between CO2 and PM2.5 emissions, both in terms of production and consumption. Fuel combustion, especially in the power generation and manufacturing sectors, is the main source of direct CO2 and PM2.5 emissions. Shabani & Shahnazi (2019) also found that ICTs contribute to CO2E in the industrial sector, while the opposite effect is observed in the transport sector.

Many factors have been examined in the literature to understand the moderating influences on the relationship between ICT and the environment. The stage of development of a country plays an important role. Danish et al. (2018) highlight the role of the stage of development, finding that ICTs degrade the environment in high-income emerging economies. Conversely, ICTs have no discernible effect on CO2E in high-income developing countries but contribute to environmental sustainability in low-income developing countries (N'dri et al., 2021). However, an important recent study has challenged the assumption that the level of CO2E (high, medium, or low) determines the environmental impact of ICTs, showing that ICTs degrade the environment in countries across the CO2E spectrum (Alataş, 2021).

Furthermore, the quality of a country's ICT infrastructure acts as an additional conditional determinant. Appiah-Otoo & Song (2021) found that the relationship between ICT and environmental sustainability is complex and varies according to the quality of ICT infrastructure. In countries with high-quality ICT infrastructure, ICTs are associated with positive environmental impacts, whereas in countries with moderate and low ICT quality, ICTs can have negative environmental impacts due to increased energy demand associated with the installation of ICT equipment. Conversely, better ICT infrastructure allows easier access to the Internet for various activities such as banking, education, e-commerce, entertainment, healthcare, and remote working, thereby increasing energy efficiency and improving environmental quality. In addition, countries with high-quality ICT tend to have advanced e-government systems, which can help reduce corruption and red tape and increase transparency, ultimately improving environmental conditions.

Finally, the overall impact of ICTs on the environment can be decomposed into three different partial effects, and it is uncertain which effect will prevail. According to Higón et al. (2017) and Shabani & Shahnazi (2019), ICTs can have three main effects on the environment: (a) a substitution effect, (b) a use effect, and (c) a cost effect. The substitution effect suggests that ICTs contribute to improving environmental quality by reducing energy consumption and CO2 emissions through various means, such as the use of email, e-books, intelligent transport systems, sharing economy platforms, traffic control cameras, smart cities, e-government, e-commerce, online education, and online communication. By enabling these alternative methods, ICTs can potentially reduce the environmental impacts associated with traditional practices. However, ICTs can also have a negative impact on the environment through lifecycle stages, including production, processing, distribution, and disposal. These stages contribute to increased energy consumption and CO2 emissions, known as the use effect. The rapid consumption of ICTs also leads to lower prices for goods and services, resulting in increased product demand, energy consumption and CO2 emissions, known as the cost effect.

Furthermore, Wang et al. (2022) show that ICT agglomeration has a positive direct effect on carbon emissions. However, this effect can be mitigated indirectly through the promotion of technological innovation, which can lead to the development and adoption of more environmentally friendly practices and solutions.

In summary, the environmental impact of ICTs is complex and multifaceted. While ICTs offer potential benefits through the substitution effect, their use and associated life cycle stages can have negative environmental impacts. The overall outcome depends on the interaction of these partial effects, making it difficult to draw a definitive conclusion.

HYPOTHESES AND ESTIMATION STRATEGY

Given the growing global concerns about energy sustainability and environmental protection, the integration of Information and Communication Technologies (ICTs) has emerged as a promising tool for transformative change. This study attempts to unravel the multiple effects of ICT adoption on energy dynamics and emissions.

As outlined in the introductory section, we test three different hypotheses.

(H.1) ICTs as a tool for energy conservation - The first hypothesis is that the adoption of ICT technologies can lead to significant conservation of energy resources. This idea is based on the premise that ICT enables more precise and adaptive control of energy consumption in various sectors. For example, smart grid systems and intelligent energy management algorithms enabled by ICT solutions can dynamically adjust energy distribution, reduce waste, and optimise consumption patterns. By investigating this hypothesis, we seek to determine the extent to which ICTs contribute to the overall conservation of energy resources.

(H.2) ICTs and the optimization of energy use - The second hypothesis to be tested is that the use of ICT facilitates the optimisation of energy use. This is based on the recognition that advanced digital technologies allow for improved coordination and control of energy-intensive processes. Through the application of sophisticated algorithms and predictive modelling, ICT systems can intelligently allocate and utilise energy resources, minimising waste, and maximising efficiency. By exploring this hypothesis, we aim to uncover the extent to which ICT can contribute to reshaping the energy consumption landscape.

(H.3) ICTs for the reduction of pollutant emissions - Another critical assumption concerns the potential of ICT adoption to mitigate environmental degradation by reducing pollutant emissions. This hypothesis is based on the idea that ICT, both as an innovation and a tool (used in itself) - can lead to cleaner and more efficient production processes across industries. For example, by integrating real-time monitoring, predictive analytics and automation, ICT enables companies to optimise their operations, leading to reduced emissions of harmful pollutants. Through our empirical analysis, we seek to test this effect and to draw wider implications for environmental sustainability.

Considering these hypotheses, in this version of our work, our empirical investigation will leverage the Ordinary Least Squares (OLS) approach to test these conjectures. Through this analysis, we aim to contribute insights to the discourse on the role of ICT in fostering sustainable energy practices and mitigating environmental impacts.

To test our hypotheses, we estimate three different models in which we use different dependent variables according to the hypothesis we are considering. Our general empirical model is the following:

$$X_{it} = ß_0 + ß_1 Controls_{it-1} + b_6 Internet_{it-1} + b_7 Mobile_{it-1} + b_8 Broadband_{it-1} + \lambda_f + \Phi_s \, \varepsilon_{it} \quad (1)$$

where the subscripts i and t refer to country and year respectively.

To measure the impact of ICT technologies on energy and environmental related variables, we use three different dependent variables: 1) the primary energy consumption per unit of GDP – measured in in kilowatt-hours per international dollar ($) – as a proxy of how much energy a country *c* uses at time *t* to generate one unit of GDP, denominated in international dollars reflecting the efficiency of an economy in terms of energy utilization (ENE^{GDP}_{it}); 2) the production-based CO2 emissions per dollar – measured as the annual CO2 emissions of country *i* at time *t* divided by its total annual gross domestic product (GDP) – to measure how carbon-intensive a country's economy is at time t ($CO2^{GDP}_{it}$); 3) the production-based CO2 emissions per unit of primary energy – measured as the total annual emissions of a country *c* at time *t* by its primary energy consumption – to measure how carbon-intensive a country's energy mix is (e.g., a nation predominantly dependent on coal will register substantial CO2 emissions per unit of energy, while a country endowed with a significant share of nuclear and renewable energy sources will exhibit markedly lower emissions in comparison) ($CO2^{ENE}_{it}$).

To assess the impact of ICT on energy efficiency and emission reduction, we employ a set of three distinct ICT-related variables, encompassing both utilization and infrastructure, and incorporate them with a one-year lag to address potential simultaneity concerns. Specifically, we use: the individuals using the internet as % of the population ($Internet_{it-1}$), the number of fixed broadband subscriptions per 100 capita ($Broadband_{it-1}$), and mobile cellular subscriptions per 100 capita ($Mobile_{it-1}$). To look at the effect of these variables for MENA countries, we include in the estimations the interaction with a dummy variable d_{MENA} which equals 1 if the country belongs to the UN MENA classification and to 0 otherwise.

In addition, we introduce a series of lagged control variables designed to account for factors that may exert influence on our three dependent variables. Firstly, we incorporate the urbanization rate, defined as the proportion of the total population residing in urban areas ($Urbanisation_{it-1}$). Subsequently, we include two energy-related variables to control for the extent of alternative energy utilization ($AlEnUse_{it-1}$) measured as the percentage of alternative and nuclear energy in relation to total energy consumption, as well as the level of primary energy usage prior to its transformation into other end-use fuels ($EnUse_{it-1}$). Moreover, to address variations in the economic composition of different countries, we encompass the value added in agriculture, forestry, and fishing (% of GDP) (Agr^{GDP}_{it-1}). Additionally, we account for the level of human capital in country i by considering the enrolment rate in secondary education (HC_{it-1}). Finally, we include in our model the country-specific fixed effects λ_f and year fixed effects Φ_s, to control for idiosyncratic characteristics of individual countries and account for broader temporal patterns over the study period.

DATA

To test our hypotheses, in this work we combine different data sets. Our final sample consists of 113 countries of which 15 belonging to the MENA area[1], spanning the period from 2001 to 2020. The dataset is mainly built on two data sources: the first one is the Standard Dataset proposed by the Quality of Government (QoG) Institute (University of Gothenburg), which provides country-level information and key indicators for our study related to energy consumption, production of sustainable energy, GDP, GDP per capita, and multiple indicators related to ICT infrastructure (fixed broadband subscriptions per 100 capita, mobile cellular subscriptions per 100 capita, and individuals using the internet in % of population). The other data set that we use in our analysis is the Greenhouse Gas Emissions (GGE) dataset which provides information on CO2 annual emissions sourced from the Global Carbon Project (Table 1).

Table 1. Variable description and source

Variable	Description	Data
$CO2_{it}^{GDP}$	Annual total production-based emissions of CO_2, excluding land-use change, measured in kilograms per dollar of GDP.	GGE
$CO2_{it}^{ENE}$	Annual total production-based emissions of CO_2, excluding land-use change, measured in kilograms per kilowatt-hour of primary energy consumption.	GGE
ENE_{it}^{GDP}	Primary energy consumption per unit of GDP	GGE
$Urbanisation_{it}$	People living in urban areas (% total population)	QoG - WDI
$EnUse_{it}$	Energy use (kg of oil equivalent per capita)	QoG - WDI
$AlEnUse_{it}$	Alternative and nuclear energy (% of total energy use)	QoG - WDI
Agr_{it}^{GDP}	Agriculture, forestry, and fishing, value added (% of GDP)	QoG - WDI
HC_{it}	Percentage of enrollment in secondary education	QoG - WDI
$Internet_{it}$	Individuals using the Internet (% of population)	QoG - WDI
$Mobile_{it}$	Mobile cellular subscriptions (per 100 people)	QoG - WDI
$Broadband_{it}$	Fixed broadband subscriptions (per 100 people)	QoG - WDI

[1] The MENA countries in our sample are Algeria, Bahrain, Egypt, Iran, Israel, Jordan, Kuwait, Lebanon, Morocco, Oman, Saudi Arabia, Syria, Tunisia, Turkey, and Yemen.

In Table 2, we provide descriptive statistics for our sample, while Table 3 offers descriptive statistics of the subset comprising MENA countries.

Notably, when we consider the whole sample, our first dependent variable, the CO2 emissions per unit of GDP ($CO2_{it}^{GDP}$), reveals important insights into the environmental footprint of these economies. Indeed, we find that, on average, our sample countries generate approximately 29.34 units of CO2 for every unit of GDP. This metric carries significant implications for understanding the carbon intensity of these economies. The range is extensive, spanning from a minimum of 3.9 to a maximum of 106.7, underscoring the diversity in emission profiles.

Similarly, CO2 emissions per unit of energy consumption ($CO2_{it}^{ENE}$) provide crucial insights. On average, our sample countries emit approximately 19.56 units of CO2 for every unit of energy consumed. Again, we observe considerable variability, with values ranging from 3.1 to 46.9. This metric serves as a key indicator of the efficiency of energy use and its associated environmental impact.

Turning our attention to energy-related variables, we delve into energy intensity (ENE_{it}^{GDP}). This metric, which gauges the amount of energy consumed for each unit of economic output, averages at about 1.56. This indicates that, on average, our sample countries require approximately 1.56 units of energy to produce one unit of economic output. This figure has significant implications for understanding the energy efficiency of these economies.

Furthermore, we explore the level of urbanization ($Urbanisation_{it}$), which stands at an average of roughly 67.91. This provides a valuable lens through which to view the extent of urban development within these countries. The range spans from 16.21 to 100, signifying diverse urbanization profiles.

Table 2. Descriptive statistics: full sample

Variable	Obs	Mean	Std. Dev.	Min	Max
$CO2_{it}^{GDP}$	1105	29.343	15.665	3.9	106.7
$CO2_{it}^{ENE}$	1105	19.562	6.014	3.1	46.9
ENE_{it}^{GDP}	1105	1.563	.758	.276	5.442
$Urbanisation_{it}$	1105	67.913	17.65	16.208	100
$EnUse_{it}$	1014	2941.022	3070.058	123.751	21420.629
$AlEnUse_{it}$	1014	9.878	11.309	0	50.023
Agr_{it}^{GDP}	1105	6.716	7.036	.036	44.331
HC_{it}	1005	16.649	16.499	0	95.325
$Internet_{it}$	1105	44.273	28.121	.221	98.24
$Mobile_{it}$	1105	93.805	38.906	1.184	202.043
$Broadband_{it}$	1105	12.014	12.124	0	45.097

Notes: Authors' own elaboration using data from QoG and GGE datasets.

In Table 3, we narrow our focus to the MENA countries. Here, we uncover distinct patterns. For instance, MENA countries tend to exhibit higher levels of CO2 emissions per unit of GDP compared to the broader sample. This may signify unique economic structures and development trajectories within this region.

Table 3. Descriptive statistics: MENA countries

Variable	Obs	Mean	Std. Dev.	Min	Max
$CO2_{it}^{GDP}$	106	35.568	13.27	19.2	88.7
$CO2_{it}^{ENE}$	106	23.359	3.28	14.8	30.5
ENE_{it}^{GDP}	106	1.62	.879	.686	5.442
$Urbanisation_{it}$	106	75.366	17.042	29.49	100
$EnUse_{it}$	98	3252.651	3631.704	228.123	11757.025
$AlEnUse_{it}$	98	1.002	1.46	0	6.654
Agr_{it}^{GDP}	106	6.489	6.268	.16	26.86
HC_{it}	84	18.255	18.634	0	61.257
$Internet_{it}$	106	34.989	24.839	1.248	93.478
$Mobile_{it}$	106	84.595	46.428	9.859	202.043
$Broadband_{it}$	106	5.193	7.516	0	27.675

Notes: Authors' own elaboration using data from QoG and GGE datasets.

Notably, ICT penetration in MENA countries, as indicated by the percentage of individuals using the internet relative to the total population ($Internet_{it}$), appears to be somewhat lower compared to the overall sample. This observation suggests potential disparities in access to information and communication technologies.

Additionally, mobile cellular subscriptions per 100 capita ($Mobile_{it}$) and fixed broadband subscriptions per 100 capita ($Broadband_{it}$) exhibit notable differences. These figures indicate variations in technology adoption rates, which can have significant implications for economic development and connectivity within the MENA region.

These observations collectively indicate that MENA countries tend to have lower ICT penetration levels compared to the entire sample, potentially signifying a lag in ICT adoption and infrastructure development in these regions. Additionally, they exhibit distinct patterns in CO2 emissions and energy-related variables, which may have implications for energy sustainability and environmental policies in the MENA region.

ICTS, ENERGY CONSERVATION, OPTIMIZATION, AND POLLUTANT EMISSIONS: WHERE ARE MENA COUNTRIES?

A CLOSER LOOK AT ICTS' ADOPTION IN MENA COUNTRIES

In this section, we look at which stage the MENA is at with respect to the ICT diffusion indicators we will use in our empirical analysis. As previously said, we consider the fixed broadband subscriptions per 100 capita, mobile cellular subscriptions per 100 capita, and individuals using the internet in % of population.

Table 4. ICT diffusion indicators, per 100 inhabitants, 2015

Country	$Internet_{it}$	$Mobile_{it}$	$Broadband_{it}$
Algeria	38.20	109.32	5.74
Bahrain	93.48	184.93	18.58
Egypt	37.82	96.21	3.92
Iran	45.33	90.74	8.08
Israel	77.35	132.00	27.14
Jordan	54.22	145.33	3.26
Kuwait	82.00	196.09	1.41
Morocco	57.08	124.28	3.31
Oman	73.53	155.76	5.47
Saudi Arabia	69.62	161.21	19.35
Syria	29.98	74.52	3.80
Tunisia	46.50	126.29	4.97
Turkey	53.74	92.46	11.93
United Arab Emirates	90.50	201.22	13.84
Yemen	24.09	52.68	1.39

Notes: Authors' own elaboration using data from QoG. In this table, data on ICTs proxies used in the empirical analysis are shown for the 2015.

The level of ICT diffusion varies greatly among the MENA countries (Table 4). For example, the number of Internet users varies from around 24 per 100 inhabitants in Yemen to 93% in Bahrain. Another important indicator is fixed broadband subscriptions, which provide the infrastructure for high-speed internet connections, enabling efficient data transmission and access to a wide range of online services. In this case, the differences between our samples are more pronounced: Kuwait shows only 1% of fixed broadband subscriptions per 100 capita, whereas Israel has 27%. The average of fixed broadband subscriptions per 100 capita in our MENA countries is below 8%.

The case of mobile cellular subscriptions is extremely important for the quality of life in these countries: the level of mobile subscriptions is quite high in all countries in our sample. In the lowest one (Yemen), there were 53 mobile cellular subscriptions per 100 inhabitants, but in ten other MENA countries (United Arab Emirates, Kuwait, Bahrain, Saudi Arabia, Oman, Jordan, Israel, Tunisia, Morocco, and Algeria), mobile cellular subscriptions exceeded 100 percent. Mobile subscriptions are particularly relevant in regions where fixed-line infrastructure may be limited.

The importance of different indicators, and their connection to economic and societal factors, varies depending on the "development trajectory" and maturity of countries' Information Societies (Tsang et al., 2011). For example, in some countries, mobile phones play a crucial role in establishing social and economic connections and are an essential part of the economy and society. Additionally, the predominant mode of Internet connection impacts specific indicators. In many countries, low levels of private Internet subscriptions may underestimate access because individuals, particularly in urban areas, have abundant and affordable access through wireless local area networks like Wi-Fi in cafes and other public locations. In such countries, private fixed-line telephone and Internet subscriptions are lagging indicators of the actual adoption and usage levels.

To have an idea of the evolution over time of ICTs, in Figure 1, we present the temporal evolutions of key ICT indicators used in our analysis, focusing on MENA countries in comparison to the Rest of the World (RoW).

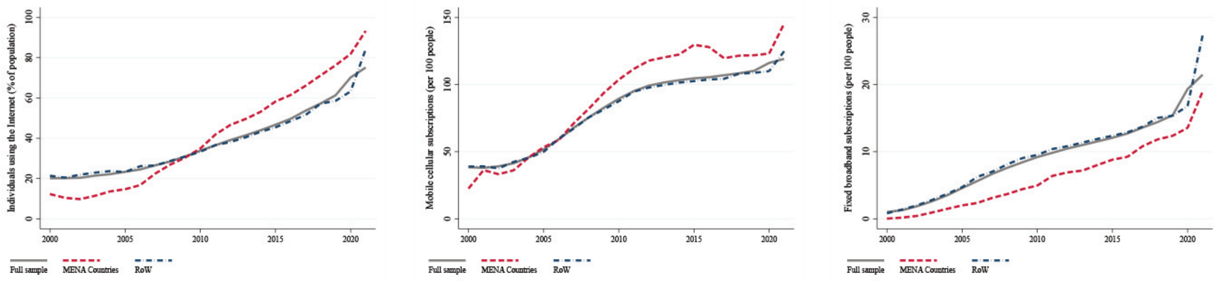
Figure 1 (a) displays the evolution of internet usage, measured as the percentage of individuals using the internet as a share of the total population, from 2000 to 2020. In this case, the MENA countries show on average higher levels of internet usage with respect to the global mean especially after 2006.

Furthermore, when we look at Figure 1 (b), it illustrates the evolution of internet usage, measured as the percentage of individuals using the internet as a share of the total population, from 2000 to 2020. MENA countries exhibited lower initial rates of mobile cellular subscriptions, trailing behind the RoW. However, from approximately 2006 onwards, MENA experienced a sharper surge in mobile subscriptions, showing higher averages with respect to the average levels of the rest of the World, and showing an acceleration in mobile technology adoption.

Finally, Figure 1 (c) illustrates the progression of broadband subscriptions per 100 individuals from 2000 to 2021. Notably, the RoW consistently demonstrated higher rates of broadband adoption compared to MENA throughout the entire period. However, from around 2007, MENA experienced a substantial surge, narrowing the gap with the RoW. This surge indicates a notable shift in broadband adoption dynamics within the MENA region.

However, a deeper heterogeneity decomposition, considering other country groups, is essential for a comprehensive understanding.

Figure 1. ICTs evolution: MENA vs RoW

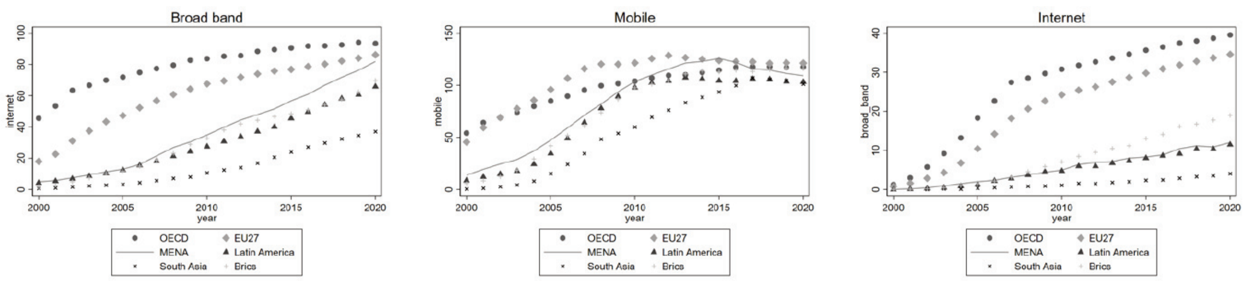


(a) (b) (c)

Notes: Figure (a) shows the evolution of the Internet usage, measured as the Individuals using internet as share of population. Figure (b) shows the evolution of the number of mobile cellular subscription per 100 people. Figure (c) shows the number of broadband subscriptions per 100 people. In all figures, the solid gray line shows the average for the whole sample, the red dashed line indicates the average for the MENA countries, and the blue short-dashed line the average for the rest of the World. All the figures show moving averages including 1 year before and 1 year after each date.

In Figure 2, indeed, we dig into the heterogeneity by country groups, and we compare the development from 2000 to 2020 of our main indicators, comparing the evolution between the MENA region and the mean for other country categories, namely OECD, BRICS, EU27, South East Asia, and Latin America. The MENA area appears to be far from the level of both OECD and EU27 countries and there are still significant disparities. However, we observe that all ICT infrastructure indicators have grown during this reference period. Particularly, the population with both access to a fixed broadband and mobile network in the MENA area exhibits important infrastructural growth.

Figure 2. ICTs indicators: evolution over time by country group



(a) (b) (c)

Notes: Figure (a) shows the evolution of the Internet usage, measured as the Individuals using internet as share of population. Figure (b) shows the evolution of the number of mobile cellular subscription per 100 people. Figure (c) shows the number of broadband subscriptions per 100 people.

On the contrary, the mobile network shows a different pattern, as all the areas we have considered show a trend towards values close to 100 (with an increase of 7 times in 20 years). This suggests that the mobile network has now become nearly universal, allowing nearly everyone to access the Internet. Nevertheless, it's worth noting that this infrastructure is often used as a substitute for the fixed network: in 2020, 82% of households in this area have access to the Internet from a fixed network and 109% from a mobile network (OECD 93% and 117% respectively).

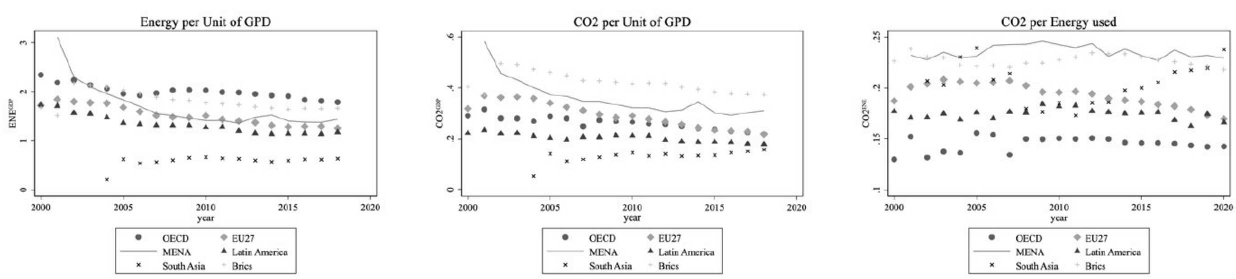
In conclusion, considering the observed trends in ICT infrastructure and usage across the MENA region, it is evident that targeted investments are pivotal for harnessing the full potential of ICTs. The progress made in internet accessibility and usage, particularly when compared to the RoW, provides valuable insights. This will enable a nuanced comparison of MENA countries with diverse global counterparts. Notably, broadband subscriptions have witnessed a surge in MENA countries, narrowing the gap with the RoW. Strategically directing resources towards sustaining and advancing mobile technology adoption is crucial, given the region's commendable progress in this domain. By prioritizing these areas and leveraging the strengths demonstrated in the data, MENA countries can position themselves as dynamic players in the global ICT landscape, driving innovation, economic growth, and social development.

ENERGY DYNAMICS, POLLUTANT EMISSIONS: SUGGESTIVE LINKS WITH ICTS

In this section, we look at the evolution of what we consider as dependent variables in our Eq. 1. In particular, we look at the energy intensity, measured as the primary energy consumption per unit of GDP, the CO2 intensity, measured as the production-based CO2 emissions per dollar of GDP, and, finally, at the CO2 emissions per unit of primary energy. These variables, according to what we outlined in the previous sections, are likely to be affected by the ICT in different ways to measure the role of ICTs in increasing energy consumption and optimization, and in reducing pollutants.

So, in Figure 3, we present the trend in Energy Intensity, CO2 intensity and CO2 per energy use. If we look, for example, at CO2 intensity (Fig. 3, panel (b)), it is noteworthy that in all reference groups, this indicator shows a decreasing trend, indicating that economies are learning to produce with lower pollution levels. Specifically, the BRICS exhibit the most significant reduction in CO2 intensity in absolute terms (-33%), while China seems to have initiated a serious policy aimed at reducing climate change (Chen & Bian, 2023). However, the MENA countries appear to be the only area that has not remarkably reduced its emissions per unit of GDP, as the values remain constant over the two decades under consideration (-0.15%).

Figure 3. Energy Intensity, CO2 intensity and CO2 per energy use: evolution over time by country group



(a) (b) (c)

Notes: Figure (a) shows the evolution of the Energy intensity, measured as the energy use per unit of GDP. Figure (b) shows the evolution of the CO2 intensity, measuring the CO2 emissions per unit of GDP. Figure (c) shows the CO2 emissions per unit of energy used.

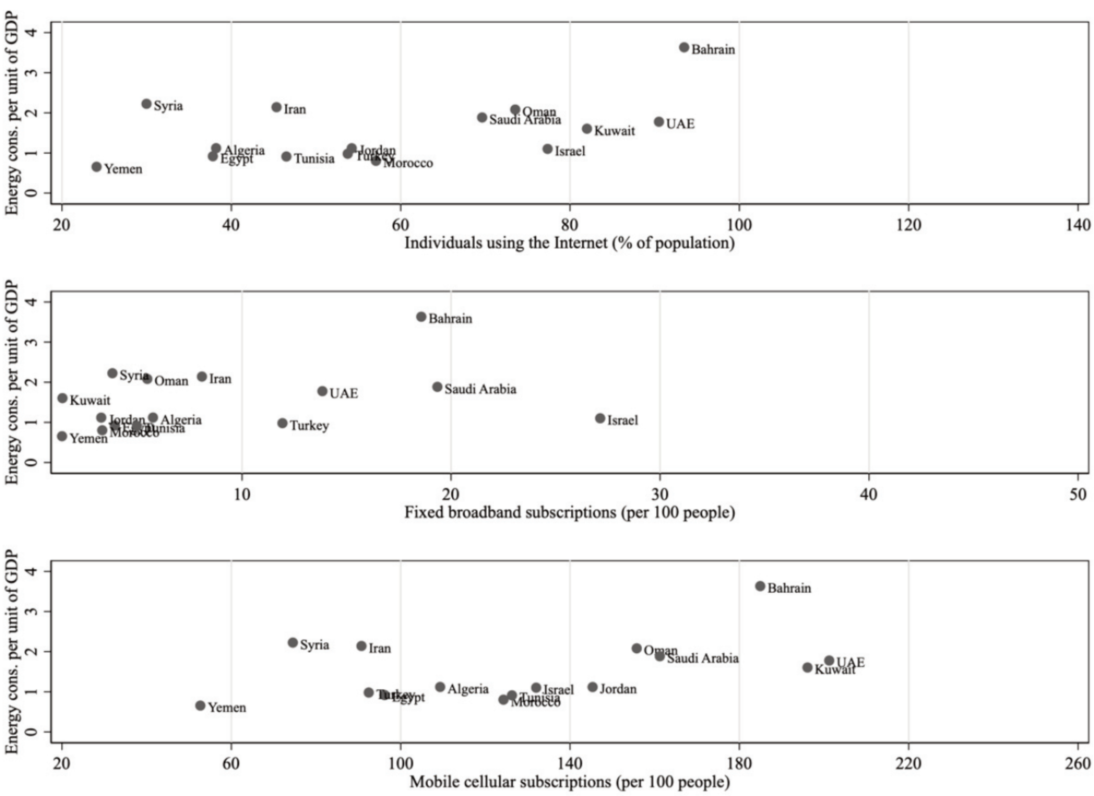
The analysis presented so far shows the need for targeted policies aimed at reducing emissions in the MENA region. Given the distinctive economic landscape of MENA countries, characterized by a significant reliance on energy-intensive industries, the adoption of new technologies emerges as a pivotal strategy. Policymakers should incentivize the deployment of energy-efficient technologies across sectors such as manufacturing, transportation, and construction.

ICTs present a transformative toolset for advancing emission reduction goals in MENA countries. These technologies facilitate real-time monitoring of energy consumption, enabling businesses and households to identify opportunities for efficiency improvements.

In addition, ICTs enable the widespread dissemination of information on sustainable practices, thereby empowering individuals, and businesses to make informed decisions regarding energy consumption. Smart city initiatives, driven by ICTs, can optimize urban planning and design for energy efficiency, promoting sustainable urbanization.

Moreover, the use of data analytics and artificial intelligence, harnessed through ICT platforms, can unlock insights for optimizing industrial processes and supply chain management. Predictive analytics can help businesses anticipate energy demands and implement proactive measures to mitigate consumption.

Figure 4. Energy intensity and ICTs adoption - MENA countries, 2015

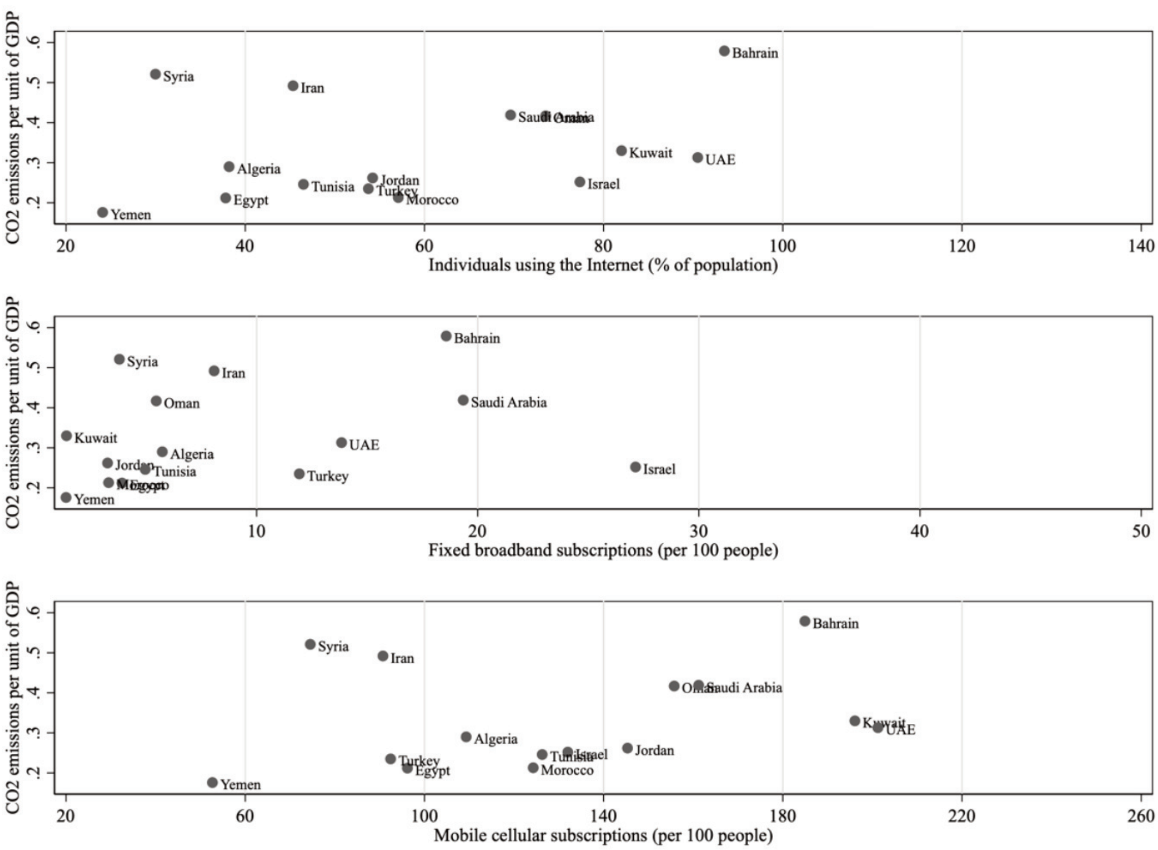


Notes: Authors' own elaboration.

To have a first glance of how ICTs and energy and pollutants are correlated, we start from Figure 4 showing a scatter plot. In this case, the graphs do not show a strong correlation path among the values in 2015 for MENA countries, but countries more linked to natural resources tend to have higher primary energy consumption per unit of GDP.

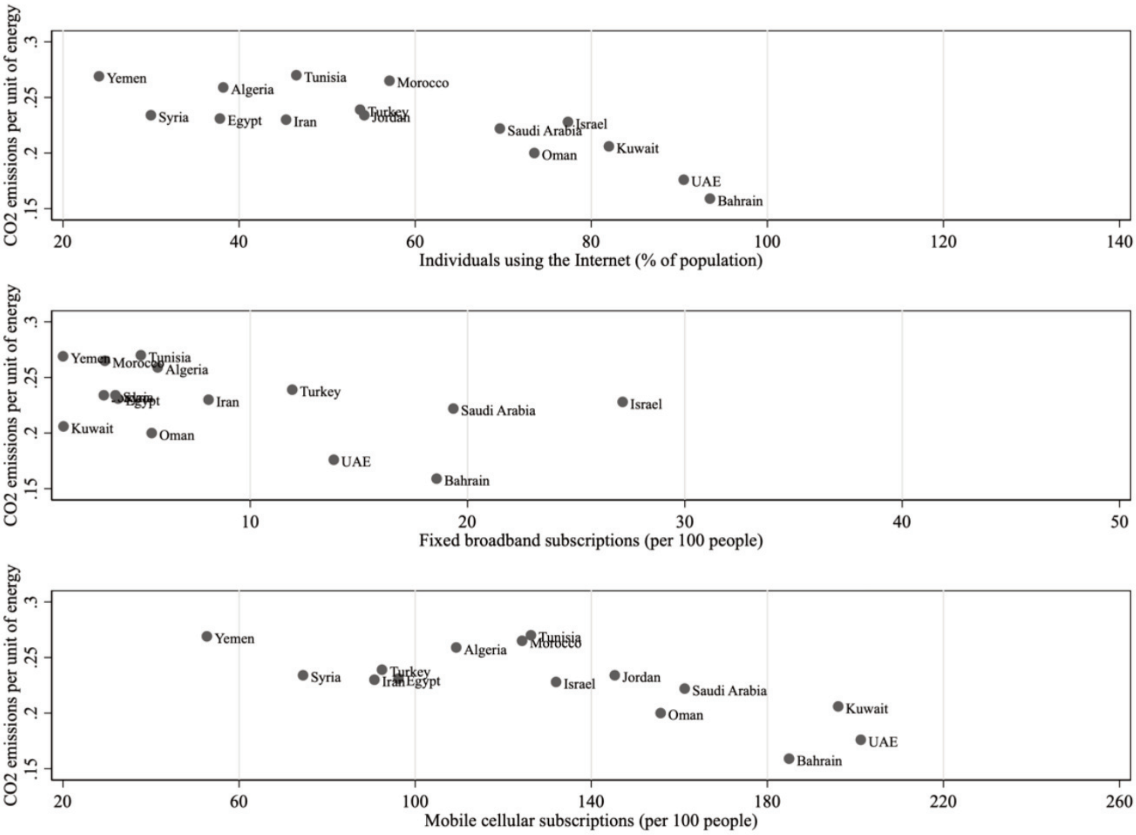
Furthermore, Figure 5 plots show ICTs and CO2 intensity for MENA countries in 2015. The graphs do not show a strong relationship between these variables, particularly in the case of Internet access and mobile subscriptions, where this relationship seems to be entirely non-existent or weak. However, there appears to be a connection between fixed broadband subscriptions and CO2 intensity. Israel is undoubtedly the most advanced country in the MENA area, and consequently, its CO2 intensity aligns with that of more advanced countries. Moving from right to left, we can see Turkey and the United Arab Emirates, which, together with Israel, have the least environmental impact per unit of GDP produced. Finally, in the case of CO2 emission per unit of energy used (Figure 6), the pattern appears slightly clearer with countries with higher adoptions of ICTs showing lower values of CO2 emissions.

Figure 5. CO2 intensity and ICTs and ICTs adoption - MENA countries, 2015



Notes: Authors' own elaboration.

Figure 6. CO2 per energy used and ICTs adoption - MENA countries, 2015



Notes: Authors' own elaboration.

RESULTS

In this section, we present our results from estimating the Eq. 1 with the fixed effects method for various variables. First, Table 6 provides the results of our estimations, shedding light on the ICTs and energy efficiency, testing the H.1 and H.2 outlined in Section 3. The dependent variable, primary energy consumption per unit of gross domestic product (measured in kilowatt-hours per dollar of GDP in 2011), serves as a crucial metric in assessing the efficiency of energy utilization.

Looking at the coefficients of the controls, several key insights emerge. Notably, urbanization exhibits a positive albeit modest effect on energy consumption per GDP, implying that as countries urbanize, there is a marginal increase in energy use relative to economic output. This result aligns with the conventional understanding of urban centres as hubs of economic activity and, consequently, higher energy demand.

Furthermore, the alternative energy use introduces a noteworthy dynamic. A positive coefficient indicates that alternative energy use positively impacts energy efficiency, signifying the potential of diversified energy sources in contributing to a more sustainable economic model. This observation underscores the importance of promoting and investing in alternative energy technologies, which can yield substantial gains in energy conservation (Acheampong, 2018).

Turning to the role of ICTs, the coefficients associated with internet and mobile subscriptions merit special attention. The negative coefficient for $Internet_{it}$ implies that, on average, higher internet usage is associated with lower energy intensity. This intriguing finding suggests that digitalization, particularly through internet adoption, may lead to enhanced energy efficiency, potentially through increased automation and streamlined processes.

Moreover, the interaction terms with the MENA dummy variable provide critical insights into the region's unique dynamics. For instance, the negative coefficient for $Internet_{it} x\ d_{MENA}$ indicates that the relationship between internet usage and energy intensity differs for MENA countries compared to the rest of the sample.

Moving to broadband subscriptions ($Broadband_{it}$), the positive coefficient seems to counterintuitively suggest that higher broadband penetration is associated with increased energy intensity. However. the interaction term $Broadband_{it} x\ d_{MENA}$ introduces an interesting dimension. The negative coefficient indicates that the relationship between broadband adoption and energy intensity differs for MENA countries compared to the rest of the sample underscoring the beneficial effect in terms of reduction of energy use for MENA countries, as well as the need for region-specific policies that address the unique challenges and opportunities in leveraging broadband technologies for energy conservation. Finally, the negative coefficient for $Mobile_{it}$ suggests that higher mobile penetration is associated with lower energy intensity. This finding aligns with the notion that mobile technologies enable more efficient communication and resource management, potentially leading to reduced energy consumption. The interaction term $Mobile_{it} x\ d_{MENA}$, albeit not significant, preserves the sign of the coefficient. In summary, the analysis of broadband and mobile subscriptions, along with their interactions with the MENA dummy variable, provides nuanced insights into the relationship between ICT adoption and energy efficiency.

Table 6. The effect of ICTs on Energy per GDP

	OLS				
	(1)	(2)	(3)	(4)	(5)
Urbanization$_{it}$	0.005	-0.000	0.010	0.009	0.008
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Energy Use$_{it}$	0.000***	0.000***	0.000***	0.000***	0.000***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
AltEnUse$_{it}$	0.009**	0.009**	0.007	0.009*	0.008*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Agr_gdp$_{it}$	0.011	0.014	0.006	0.011	0.007
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
HC$_{it}$	-0.006	-0.004	-0.006	-0.005	-0.006
	(0.01)	(0.00)	(0.01)	(0.01)	(0.00)
Internet$_{it}$		-0.007**			-0.008**
		(0.00)			(0.00)
Internet$_{it}$ x d_{MENA}		-0.002			0.006
		(0.00)			(0.01)
Mobile$_{it}$			-0.002**		-0.001*
			(0.00)		(0.00)
Mobile$_{it}$ x d_{MENA}			-0.001		-0.000
			(0.00)		(0.00)
Broadband$_{it}$				0.003	0.008
				(0.00)	(0.00)
Broadband$_{it}$ x d_{MENA}				-0.029**	-0.034**
				(0.01)	(0.01)
Country FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
N	1109	1109	1109	1109	1109
N of Countries	113	113	113	113	113
R2	0.94	0.95	0.95	0.95	0.95

Notes: Results from OLS estimation in column (1) to (5) where the dependent variable is the primary energy consumption per unit of gross domestic product, measured in kilowatt-hours per dollar of GDP (2011). Column (1) shows the results by including just the controls from Eq. 1. Columns from (2) to (4) shows results by including our variables of interest separately. Column (5) shows the results by including the ICTs variables simultaneously. All regressions include Country fixed effects and year fixed effects. Standard errors are clustered at the country level and reported in parentheses. *, **, and *** indicate statistically different from zero at the 10%, 5%, and 1% level of significance, respectively.

Table 7. The effect of ICTs on CO2 intensity

	OLS				
	(1)	(2)	(3)	(4)	(5)
$Urbanization_{it}$	0.448*	0.275	0.528**	0.443*	0.392*
	(0.25)	(0.23)	(0.26)	(0.26)	(0.23)
Energy Use_{it}	0.002***	0.002**	0.002**	0.002***	0.002**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$AltEnUse_{it}$	-0.186*	-0.198**	-0.212*	-0.189*	-0.198**
	(0.10)	(0.08)	(0.11)	(0.10)	(0.09)
Agr_gdp_{it}	-0.450*	-0.388*	-0.518**	-0.423*	-0.459*
	(0.24)	(0.21)	(0.26)	(0.25)	(0.23)
HC_{it}	-0.228	-0.189	-0.231	-0.210	-0.209
	(0.16)	(0.13)	(0.16)	(0.16)	(0.14)
$Internet_{it}$		-0.219***			-0.259**
		(0.08)			(0.10)
$Internet_{it}$ x d_{MENA}		0.007			0.163
		(0.07)			(0.19)
$Mobile_{it}$			-0.030		0.001
			(0.02)		(0.01)
$Mobile_{it}$ x d_{MENA}			-0.013		-0.021
			(0.03)		(0.04)
$Broadband_{it}$				-0.023	0.148
				(0.09)	(0.14)
$Broadband_{it}$ x d_{MENA}				-0.511**	-0.572**
				(0.30)	(0.54)
Country FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
N	1109	1109	1109	1109	1109
N of Countries	113	113	113	113	113
R2	0.93	0.94	0.93	0.93	0.94

Notes: Results from OLS estimation in column (1) to (5) where the dependent variable is the total production-based emissions of carbon dioxide (CO), excluding land-use change, measured in kilograms per dollar of GDP (2011). Column (1) shows the results by including just the controls from Eq. 1. Columns from (2) to (4) shows results by including our variables of interest separately. Column (5) shows the results by including the ICTs variables simultaneously. All regressions include Country fixed effects and year fixed effects. Standard errors are clustered at the country level and reported in parentheses. *, **, and *** indicate statistically different from zero at the 10%, 5%, and 1% level of significance, respectively.

Policymakers in MENA countries should consider targeted approaches to maximize the benefits of these technologies while addressing their potential energy implications. This may involve incentivizing energy-efficient practices in the telecommunications sector and promoting the adoption of sustainable technologies. Moreover, the findings underscore the potential of alternative energy sources and digital technologies in driving sustainable economic development.

Moving to the relationship between ICTs and CO2, we want to test the H.3 outlined in Section 3.

The results from Table 7 provide insights into the relationship between ICTs and CO2 intensity. Focusing on ICTs variables, $Internet_{it}$, when considered independently (Column 2), shows a statistically significant negative effect, indicating that higher internet penetration is associated with lower CO2 intensity. When interacted with the MENA dummy variable, the coefficient becomes non-significant, suggesting that this relationship does not significantly differ for MENA countries. $Mobile_{it}$, representing mobile subscriptions, is not statistically significant in most specifications, suggesting that mobile subscriptions may not have a strong direct effect on CO2 intensity.

$Broadband_{it}$, indicating broadband subscriptions, also shows a non-significant effect in most specifications. However, when interacted with the MENA dummy variable, a significant negative effect emerges in Column 4, indicating that the adoption of broadband technologies in MENA countries may be associated with lower CO2 intensity. This suggests that broadband technologies, when combined with the specific context of MENA countries, can potentially contribute to reduced carbon emissions. Overall, these results shed light on the nuanced relationship between ICT adoption and CO2 intensity, highlighting the importance of considering specific technologies and their interaction with regional characteristics in crafting effective policies for carbon emissions reduction.

Finally, Table 8 shows the results for the relationship between ICTs and carbon emissions per unit of energy consumption.

The ICT variables reveal intriguing insights. $Internet_{it}$, when considered independently (Column 2), exhibits a statistically significant negative effect, indicating that higher internet penetration is associated with lower emissions per unit of energy consumed. However, when interacted with the MENA dummy variable, the coefficient becomes non-significant, suggesting that this relationship does not significantly differ for MENA countries. $Mobile_{it}$, shows a statistically significant positive effect in Column 3, indicating that higher mobile subscription rates are associated with increased emissions per unit of energy consumed. However, this effect becomes non-significant when interacting with the MENA dummy variable, suggesting that the relationship may not hold uniformly for MENA countries. $Broadband_{it}$, indicating broadband subscriptions, does not exhibit a statistically significant effect in most specifications.

Table 8. The effect of ICTs on CO2 per unit of energy

	OLS				
	(1)	(2)	(3)	(4)	(5)
$Urbanization_{it}$	0.121	0.088	0.096	0.053	0.039
	(0.10)	(0.09)	(0.10)	(0.09)	(0.09)
$Energy\ Use_{it}$	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$AltEnUse_{it}$	-0.194***	-0.195***	-0.186***	-0.194***	-0.189***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Agr_gdp_{it}	-0.196*	-0.193*	-0.174	-0.165	-0.150
	(0.11)	(0.11)	(0.12)	(0.11)	(0.11)
HC_{it}	-0.040*	-0.039*	-0.039*	-0.033	-0.030
	0.02)	(0.02)	(0.02)	(0.02)	(0.02)
$Internet_{it}$		-0.033**			-0.025
		(0.01)			(0.02)
$Internet_{it}$ x d_{MENA}		0.028			-0.003
		(0.03)			(0.03
$Mobile_{it}$			0.009*		0.008
			(0.01)		(0.01)
$Mobile_{it}$ x d_{MENA}			0.004		-0.000
			(0.02)		(0.02)
$Broadband_{it}$				-0.065***	-0.042
				(0.02)	(0.03)
$Broadband_{it}$ x d_{MENA}				0.071	0.116
				(0.10)	(0.15)
Country FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
N	1109	1109	1109	1109	1109
N of Countries	113	113	113	113	113
R2	0.94	0.94	0.94	0.94	0.94

Notes: Results from OLS estimation in column (1) to (5) where the dependent variable is the total production-based emissions of carbon dioxide (CO), excluding land-use change, measured in kilograms per kilowatt-hour of primary energy consumption. Column (1) shows the results by including just the controls from Eq. 1. Columns from (2) to (4) shows results by including our variables of interest separately. Column (5) shows the results by including the ICTs variables simultaneously. All regressions include Country fixed effects and year fixed effects. Standard errors are clustered at the country level and reported in parentheses. *, **, and *** indicate statistically different from zero at the 10%, 5%, and 1% level of significance, respectively.

CONCLUSION AND POLICY IMPLICATIONS

As indicated by previous studies (Niebel, 2018; Wang et al., 2022), ICT technologies are expected to contribute to a reduction in emissions and energy consumption, as well as to an increase in productivity. However, it is important to consider the complex relationships and the interplay between efficiency changes, as the adoption of ICT technologies can lead to improved utilization of economies of scale, and the potential concentration of activities in core locations which may have ambiguous effects on pollution related to economic growth.

This study delves into the intricate relationship between ICTs and environmental sustainability in the MENA region. Through an analysis encompassing various dimensions of ICT adoption and energy utilization, our findings provide valuable insights into the potential impact of technological advancements on carbon emissions and energy conservation. To summarize our findings, internet penetration, in isolation, demonstrates a significant negative effect on emissions per unit of energy consumed. When interacted with the MENA dummy variable, the relationship becomes non-significant, implying that the impact of internet adoption on emissions does not significantly deviate for MENA countries. Mobile subscriptions, on the other hand, reveal an intriguing pattern. Initially, higher subscription rates are associated with increased emissions per unit of energy consumed. However, when considering the MENA region, this effect diminishes, suggesting a distinctive dynamic in play. Finally, broadband adoption exhibits a mixed pattern, with the MENA dummy variable being non-significant on emissions intensity, implying that the impact of this internet does significantly deviate for MENA countries, showing a reduction in pollution intensity due to these ICT variables is more intense with respect to other countries, underscoring the need for targeted policy interventions.

In conclusion, the results highlight the multifaceted nature of these relationships, emphasizing the need for context-specific policies and interventions. Harnessing the potential of ICTs for environmental conservation requires a nuanced approach that considers regional dynamics, technological advancements, and energy conservation strategies. This research sets the stage for further exploration and policy formulation in the pursuit of a sustainable and technologically driven future for the MENA region.

The MENA region needs practical measures implemented without disrupting development efforts. Local air pollution and its associated health costs have led many societies, especially Asian emerging economies, to recognize the importance of adopting clean energy technologies. Environmental policy reform in Asia includes efforts to combat air pollution and decrease key pollutants, such as sulphur dioxide (SO2) and nitrogen oxides (NOX), without compromising economic growth. A new report by UN Environment Programme proposes twenty-five solutions that can significantly improve air quality on the world's most populated continent, Asia. They could also be implemented and enforced in other regions as well.

In terms of policy, we can suggest an improvement of the access to fixed broadband, reducing cost and improving the distribution of this infrastructure. In fact, in many cases, this infrastructure seems to be replaced by mobile subscription. Moreover, respecting the different cultures may have an important effect on reduction of CO2 emissions also a more inclusive society. The government can bridge the technology gap by introducing foreign capital, opening the market, and realizing the reduction of carbon emissions through ICT technology.

Policymakers in MENA countries should consider targeted approaches to maximize the benefits of these technologies while addressing their potential energy implications. The MENA region needs practical measures implemented without disrupting development efforts. This may involve incentivizing energy-efficient practices in the telecommunications sector and promoting the adoption of sustainable technologies. Moreover, the findings underscore the potential of alternative energy sources and digital technologies in driving sustainable economic development.

In conclusion, the results highlight the multifaceted nature of these relationships, emphasizing the need for context-specific policies and interventions. Harnessing the potential of ICTs for environmental conservation requires a nuanced approach that considers regional dynamics, technological advancements, and energy conservation strategies. This research sets the stage for further exploration and policy formulation in the pursuit of a sustainable and technologically driven future for the MENA region.

The further main recommendations on the ground of the likely rebound effects due to congestion related to ICT activities is to encourage institutions to innovatively develop new ICT tools such as those related to green finance, digital commerce and e-business activities, and other ICT-related service activities to stimulate the vitality of the ICT services market.

Hence, further policy recommendations are about favouring digital industrialization transformation and setting up measures to attract more high-quality ICT industries. Furthermore, the government should guide the integration of conventional and ICT industries to increase industrial synergy and also prioritize investments in green innovation and focus on subsidies and tax incentives for the ICT industry that invest in renewable energy and green technologies, as well as impose penalties for excessive carbon emissions.

The ICT industry may reduce carbon emissions from coal power generation in combination with clean technologies by promoting the use of renewable energy. Governments should establish the ICT industry cooperation zone, improve the resource sharing of local ICT industries, complement advantages, and further promote the efficient use of resources and rapid technological progress.

ICT technologies will lead to rapid technological growth and resource saving dividend, which may effectively offset the increase in carbon emissions brought about by the scale of production agglomeration in the initial period. In general, cities with higher carbon emissions already have complete foundations of ICT industry so technological innovation brought by ICT agglomeration is ineffective in mitigating carbon emissions. In addition, due to the existence of the rebound effect, cities with higher economic development level will be likely to use the high income generated by energy. Excessive agglomeration may also exert a crowding effect, leading to vicious competition within the region, it requires a large amount of supporting infrastructure constructions and relies on fossil fuels for power generation, increasing energy consumption. Given all these considerations, a strong effort is required to continue to invest in terms of capital allocation developed for the purpose of environmental protection, while slowing down the approval process for high-polluting and high-input industries and strengthening the green transformation of enterprises. Other basic policy goals are reducing the waste of resources in the process of promoting the agglomeration of ICT industries and promoting the agglomeration of ICT activities and economic factors by following standards and norms for ICT agglomeration in the future. In addition, from the perspective of the distribution characteristic of ICT agglomeration, the phenomenon of ICT agglomeration in core regions may exacerbate regional disparities. Mutual promotion and development of ICT industries and regional cooperation in environmental governance among regions are urgent. Hence, a strategy to foster digital skills shoud be based on a joint effort carried out in a coordinated manner by the North and the South Mediterranean countries. This is essential in order to prevent brain drain. In the economic application of technology, we need to take into account that a “skill biased technology change” is likely to occur which cannot benefit all people and all countries to the same time. Indeed, it can even cause inequalities between countries or people to grow, a factor that also calls for the implementation of specific development strategies.

As for the development of ICT implementation, it seems not to be rising to the challenges as many barriers are still limiting the applications. The digital revolution is likely to drastically change the economic growth and economic structure of the Mena economies and the political arena in these countries, as the political movement demonstrated during the political turmoils of 2010.

Although ICT implementation finally seems to be rising to the challenges in south shore countries, there are clearly a number of barriers still limiting applications and efficiency. First of all, multiple ICT applications require high specific skills (e-skills) that in turn require States to implement overall strategies in this sphere. Secondly, the weight of the content developed of products or services marketed via Internet in the South Mediterranean remains weak and marginal in the global scale.

Local air pollution and its associated health costs have led many societies, especially Asian emerging economies, to recognize the importance of adopting clean energy technologies. Environmental policy reform in Asia includes efforts to combat air pollution and decrease key pollutants, such as sulphur dioxide (SO2) and nitrogen oxides (NOX), without compromising economic growth. A new report by the UN Environment Programme (2023) proposes twenty-five solutions that can significantly improve air quality on the world’s most populated continent, Asia. They could also be implemented and enforced in other regions as well including the MENA region.

REFERENCES

Acheampong, A. O. (2018). Economic growth, co2 emissions and energy consumption: what causes what and where? Energy Economics, 74:677–692.

Ahmed, Z., Nathaniel, S. P., & Shahbaz, M. (2021). The criticality of information and communication technology and human capital in environmental sustainability: Evidence from Latin American and Caribbean countries. *Journal of Cleaner Production,* 286. https://doi.org/10.1016/j.jclepro.2020.125529

Alataş, S. (2021). The role of information and communication technologies for environmental sustainability: Evidence from a large panel data analysis. *Journal of Environmental Management,* 293. https://doi.org/10.1016/j.jenvman.2021.112889

Añón Higón, D., Gholami, R., & Shirazi, F. (2017). ICT and environmental sustainability: A global perspective. *Telematics and Informatics,* 34(4), 85–95. https://doi.org/10.1016/j.tele.2017.01.001

Appiah-Otoo, I., Acheampong, A. O., Song, N., & Chen, X. (2022). The impact of information and communication technology (ICT) on carbon dioxide emissions: Evidence from heterogeneous ICT countries. *Energy and Environment.* https://doi.org/10.1177/0958305X221118877

Appiah-Otoo, I., & Song, N. (2021). The impact of ICT on economic growth-Comparing rich and poor countries. T*elecommunications Policy,* 45(2). https://doi.org/10.1016/j.telpol.2020.102082

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O. U., Swartz, B., Quental, T. B., Marshall, C., McGuire, J. L., Lindsey, E. L., Maguire, K. C., Mersey, B., & Ferrer, E. A. (2011). Has the Earth's sixth mass extinction already arrived? In *Nature* (Vol. 471, Issue 7336, pp. 51–57). https://doi.org/10.1038/nature09678

BP (2022). Statistical Review of World Energy 2022 – 71st Edition.

Cardona, M., Kretschmer, T., & Strobel, T. (2013). ICT and productivity: Conclusions from the empirical literature. *Information Economics and Policy,* 25(3), 109–125. https://doi.org/10.1016/j.infoecopol.2012.12.002

Chen, K., & Bian, R. (2023). Green financing and renewable resources for China's sustainable growth: Assessing macroeconomic industry impact. *Resources Policy,* 85, 103927. https://doi.org/10.1016/j.resourpol.2023.103927

Danish, Khan, N., Baloch, M. A., Saud, S., & Fatima, T. (2018). The effect of ICT on CO2 emissions in emerging economies: does the level of income matters? *Environmental Science and Pollution Research,* 25(23), 22850–22860. https://doi.org/10.1007/s11356-018-2379-2

Dehghan Shabani, Z., & Shahnazi, R. (2019). Energy consumption, carbon dioxide emissions, information and communications technology, and gross domestic product in Iranian economic sectors: A panel causality analysis. *Energy,* 169, 1064–1078. https://doi.org/10.1016/j.energy.2018.11.062

Dogan, E., & Aslan, A. (2017). Exploring the relationship among CO2 emissions, real GDP, energy consumption and tourism in the EU and candidate countries: Evidence from panel models robust to heterogeneity and cross-sectional dependence. In *Renewable and Sustainable Energy Reviews* (Vol. 77, pp. 239–245). Elsevier Ltd. https://doi.org/10.1016/j.rser.2017.03.111

Dong, X., Jiang, Q., & Wang, J. (2021). Assessing Embodied Carbon Emission and Its Intensities in the ICT Industry: The Global Case. *Frontiers in Energy Research,* 9. https://doi.org/10.3389/fenrg.2021.685021

Fang, J., Tang, X., Xie, R., & Han, F. (2020). The effect of manufacturing agglomerations on smog pollution. *Structural Change and Economic Dynamics,* 54, 92–101. https://doi.org/10.1016/j.strueco.2020.04.003

Femia F., & Werrek C. (2021, April 30). Drought is Leading to Instability and Water Weaponization in the Middle East and North Africa. T*he Center for Climate and Security.*

Fong, M. W. L. (2009). Digital Divide Between Urban and Rural Regions in China. *The Electronic Journal of Information Systems in Developing Countries,* 36(1), 1–12. https://doi.org/10.1002/j.1681-4835.2009.tb00253.x

Haini, H. (2021). Examining the impact of ICT, human capital and carbon emissions: Evidence from the ASEAN economies. *International Economics,* 166, 116–125. https://doi.org/10.1016/j.inteco.2021.03.003

Kahn, M. E. (2015). Review: A Review of "The Age of Sustainable Development" by Jeffrey Sachs Reviewed Work(s): The Age of Sustainable Development by Jeffrey Sachs. *Source: Journal of Economic Literature,* 53(3), 654–666. https://doi.org/10.1257/jel.52.l.654

Lahouel, B.B., Lotfi T., Younes B.Z., Shunsuke M., (2021) Does ICT change the relationship between total factor productivity and CO2 emissions? Evidence based on a nonlinear model, Energy Economics, Volume 101, 105406, doi.org/10.1016/j.eneco.2021.105406.

Lee, C. C., He, Z. W., & Xiao, F. (2022). How does information and communication technology affect renewable energy technology innovation? International evidence. *Renewable Energy,* 200, 546–557. https://doi.org/10.1016/j.renene.2022.10.015

Lee, C. K. M., Zhang, S. Z., & Ng, K. K. H. (2017). Development of an industrial Internet of things suite for smart factory towards re-industrialization. *Advances in Manufacturing,* 5(4), 335–343. https://doi.org/10.1007/s40436-017-0197-2

Li, Y., Shi, X., Emrouznejad, A., & Liang, L. (2017). Environmental performance evaluation of Chinese industrial systems: a network SBM approach. In *Journal of the Operational Research Society.*

Liu, S., He, N., Shi, Y., & Li, G. (2021). The roles logistics agglomeration and technological progress play in air pollution — New evidence in sub-regions of Chongqing, China. *Journal of Cleaner Production,* 317. https://doi.org/10.1016/j.jclepro.2021.128414

Lu, W. C. (2018). The impacts of information and communication technology, energy consumption, financial development, and economic growth on carbon dioxide emissions in 12 Asian countries. *Mitigation and Adaptation Strategies for Global Change,* 23(8), 1351–1365. https://doi.org/10.1007/s11027-018-9787-y

Moyer, J. D., & Hughes, B. B. (2012). ICTs: Do they contribute to increased carbon emissions? *Technological Forecasting and Social Change,* 79(5), 919–931. https://doi.org/10.1016/j.techfore.2011.12.005

Nguyen, T. T., Pham, T. A. T., & Tram, H. T. X. (2020). Role of information and communication technologies and innovation in driving carbon emissions and economic growth in selected G-20 countries☆. *Journal of Environmental Management,* 261. https://doi.org/10.1016/j.jenvman.2020.110162

Oughton E., & Comini N. (2022, January 11). How broadband infrastructure impacts greenhouse gas emissions: A Chile case study. *Digital Development.*

Salahuddin, M., Alam, K., & Ozturk, I. (2016). The effects of Internet usage and economic growth on CO2 emissions in OECD countries: A panel investigation. In *Renewable and Sustainable Energy Reviews,* Vol. 62, pp. 1226–1235). Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.04.018

Shabani, D.Z., & Shahnazi, R., **(2019). "Energy consumption, carbon dioxide emissions, information and** communications technology, and gross domestic product in Iranian economic sectors: A panel causality analysis," Energy, Elsevier, vol. 169(C), pages 1064-1078.

Tsang, F., Yaqub, O., van Welsum, D., Thompson-Starkey, T. G., & Chataway, J. (2011). *The impact of information and communication technologies in the Middle East and North Africa.* www.rand.org

UN Environment Programme (2023), Keeping the promise, UNEP annual report.

Wang, J., Dong, X., & Dong, K. (2022). How does ICT agglomeration affect carbon emissions? The case of Yangtze River Delta urban agglomeration in China. *Energy Economics,* 111. https://doi.org/10.1016/j.eneco.2022.106107

Wang, J., Jiang, Q., Dong, X., & Dong, K. (2021). Decoupling and decomposition analysis of investments and CO2 emissions in information and communication technology sector. *Applied Energy,* 302. https://doi.org/10.1016/j.apenergy.2021.117618

Wang, S., Tang, Y., Du, Z., & Song, M. (2020). Export trade, embodied carbon emissions, and environmental pollution: An empirical analysis of China's high- and new-technology industries. *Journal of Environmental Management,* 276. https://doi.org/10.1016/j.jenvman.2020.111371

WB and IHME (2016). The cost of air pollution: strengthening the economic case for action.

Wolf, M. J., Emerson, J. W., Esty, D. C., Sherbinin, A. d., and Wendling, Z. A. (2022). 2022 Environmental Performance index (EPI) Results. T*echnical report, New Haven, CT: Yale Center for Environmental Law & Policy.*

Wu, J., Xu, H., & Tang, K. (2021). Industrial agglomeration, CO2 emissions and regional development programs: A decomposition analysis based on 286 Chinese cities. *Energy,* 225. https://doi.org/10.1016/j.energy.2021.120239

Yang, S., Chen, B., & Ulgiati, S. (2016). Co-benefits of CO2 and PM2.5 Emission Reduction. *Energy Procedia,* 104, 92–97. https://doi.org/10.1016/j.egypro.2016.12.017

Zhao, J., Zhao, Z., & Zhang, H. (2021). The impact of growth, energy and financial development on environmental pollution in China: New evidence from a spatial econometric analysis. *Energy Economics,* 93. https://doi.org/10.1016/j.eneco.2019.1045

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