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The ICT, Financial Development, Energy Consumption and Economic Growth Nexus in MENA Countries: Panel CS-ARDL Evidence

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Abstract

This paper analyzes the nexus between consumption of renewable and non-renewables energies, financial development, diffusion of information and communication technology (ICT) and economic growth in the MENA countries. We employ a cross-section augmented autoregressive distributed lag (CS-ARDL) modeling approach to analyze the effect of our explanatory variables on economic growth. We find a positive impact of renewable and non-renewable energies on economic growth. Financial development is related negatively to economic growth which may be explained among other things, by a weak financial sector, macroeconomic volatility and financial crises, or the existence of non-linear relationships. We find a positive and statistically significant influence of ICT on GDP. Renewable energies and diffusion of ICT can be considered important determinants of improved economic activity, job creation and create jobs and a better environment.

Keywords: ICT, financial development, renewable and non-renewable energy consumption, MENA, dynamic panel, CS-ARDL

1. Introduction

The recent economic and financial crises, political instability - both internal and external, climate change, the energy deficit, biodiversity loss and the rapid and pervasive expansion of information and communication technologies (ICT) are posing continuing challenges for all major economies but especially Middle East and North African (MENA) countries. However, these issues must not divert MENA countries from their economic and environmental efforts to adapt to climate change and achieve sustainable and inclusive development.

Renewable energies are considered vital to reduce consumption of fossil energy, strengthen the energy security of MENA countries and prevent global warming (Amirnejad et al., 2021; Belaid and Youssef, 2017; Ben Cheikh, et al, 2021; Charfeddine and Kahia, 2019; Erdogan et al., 2019; Farhani et al., 2014; Gorus and Aslan, 2019; Kahia et al., 2017; Komendantova et al, 2012; Omri, 2013; Omri et al., 2015; Tang and Abosedra, 2014). Therefore, in discussions of socio-economic development in emerging countries, the issue of energy is central , and since the industrial revolution intensive use of energy has been an essential component of economic growth. The intensive use of energy is directly related to the accumulation of capital and the availability of sufficient and reliable sources of energy and has repercussions for the production function. The coefficient of this relationship was explored by Kraft and Kraft (1978) who found a positive relationship between energy consumption and economic growth especially for developing countries. However, this relationship suggests the possibility to envision energy conservation policies that do not have negative effects on economic growth. Several studies argues that energy consumption and economic growth produce considerable pressure on environmental quality (Arouri et al., 2012; Omri et al., 2014)

Kraft and Kraft's (1978) study spawned a strand of academic research on identifying the optimal configuration of energy conservation policies in a context of climate change and resource restrictions, able to satisfy growing global economic demand caused by population

growth and urbanization. Energy supply needs to grow at the same rate as demand for energy which is determined by structural changes in technology and the ability to produce more using the same or fewer resources: that is, total efficiency in the resources use and a shift in the production frontier. The production frontier is linked directly to the factors of production which include increasingly scarce and (in relative terms) expensive energy supply. The context includes environmental preservation and the medium and long-term impacts of climate change which are threatening biodiversity. This means that economic development policies must focus on energy efficiency and be a priority for developing countries. There needs to be reduced dependence of production on energy resources and reduced energy waste based on greater energy efficiency; creation of innovative products; better integration of consumers in the system; and behavioral changes in consumption. The energy transition is a huge challenge for MENA countries but must be tackled regardless of the costs: for renewable energies to assume a major role in the progress of emerging countries, their development must be concerted, progressive and controlled by public actors.

The problems related to accelerating the energy transition while simultaneously ensuring the highest possible levels of economic growth could depend on the catalyzing roles played by ICT and financial development. The quite spectacular increase in the diffusion of ICT in all economic sectors has been accompanied by a great deal of research on their contribution to economic growth, reducing CO2 emissions and reducing energy consumption and carbon footprint. The optimists consider them as the means to allow different nations to both achieve economic growth and promote the energy transition. They see these benefits as accruing from progress in the development of software and hardware. ICT also allow emissions reductions in diverse sectors ranging from building management to teleworking, without a major technological revolution. The less optimistic believe that promoting use of ICT will increase the digital divide between urban and rural areas, rich and poor people, and different generations,

and consider that in many cases, energy efficiency is not the main objective being pursued. To assess the ICT carbon footprint and their relationship with economic growth we need to address two questions: (1) what is the real impact of ICT on wealth creation? and (2) what is the contribution of ICT to energy efficiency and the energy transition?

The results of energy conservation efforts, and especially use of renewables and improved energy efficiency, are likely to be observable only after a period of several years; also, ICT-based solutions can have high initial investment/installation costs. Thus, much of the research focuses on whether financial development could accelerate and support investment in energy-efficient facilities and processes, and the energy transition.

The present paper examines the nexus between consumption of renewable and non-renewables energies, financial development, diffusion of ICT and economic growth in the MENA countries. We employ advanced econometric procedures to identify relationships among the variables. We use a cross-section augmented autoregressive distributed lag (CS-ARDL) modeling approach to analyze the effect of our explanatory variables on economic growth. We provide three main findings. First, a positive impact of renewable and non-renewable energies on economic growth, meaning that it is crucial that MENA economies focus on energy and ensure their energy security. Second, financial development is negatively related to economic growth which might be due to a weak financial sector, macroeconomic volatility and financial crises or the existence of non-linear relationships among other reasons. Third, there is a positive and statistically significant influence of ICT on GDP, meaning that MENA countries should continue to invest in ICT to enable their full potential to support economic growth.

The paper is structured as following. Section 2 provides the literature review, section 3 describes the methodology and the data, section 4 discusses the results and the main findings, and section 5 offers some conclusions.

2. Literature review

Kraft and Kraft's (1978) work sparked nearly four decades of work on the relationship between energy use and economic growth. More recently, there has been a focus on the nexus between ICT, development, energy consumption and economic growth. The findings from these studies depend on the variables chosen, the model specification, the study period and the econometric methodology used to analyze the causality between consumption of (renewable and non-renewable) energy and the explanatory variables (growth, development and pollution). Thus, there is there is no consensus in the literature on these relationships. Ozturk's (2010) review identified almost 40 different studies using different variables and econometric techniques, and based on different data while Anwar et al. (2019) provide 27,152 bibliographic references cited by 344 authors in 1,165 articles dealing with the energy-growth nexus.

The related literature can be categorized according to the results obtained for the causal relationship between the variables.

The first strand of work focuses on the relationship between energy consumption and economic growth and generally provides four main findings. First, results that support the growth hypothesis which involves unidirectional causality from energy consumption to economic growth, suggesting that lower consumption of energy would have negative impacts on economic growth (Chen et al., 2016; Le and Quah, 2018; Narayan and Russell, 2008). Second, results that support the idea of a feedback effect (two-way causality), and find a bidirectional causality between energy consumption and economic growth, supporting the notion that an active fiscal policy (taxes or subsidies) can have a positive effect on economic growth which in turn, will have a major impact on energy consumption (Ali et al., 2018; Cai et al., 2018; Eren et al., 2019; Kahia et al., 2016; Shahbaz et al., 2013). Third, evidence in favor of the conservation hypothesis which assumes that since the economy is not totally dependent on energy, governments will be able to adopt energy conservation policies that have minimal

effects on economic growth (Le and Quah, 2018; Pao and Chen, 2019; Shahbaz et al., 2018). Fourth, research results that find no causality in any direction (neutrality hypothesis), and thus consider that conservative or expansionary policies that try to rationalize energy consumption will have a negligible effect on economic growth (Saidi and Ben Mbarek, 2016). Total energy consumption as the explanatory variable tends to be employed as or decomposed into renewable and non-renewable energy consumption.

The second strand of work investigates the financing of the economy; the financial development-economic growth nexus has been the subject of much theoretical and empirical analysis. The theory underlying this relationship has its roots in the works of Schumpeter (1934), and later, McKinnon (1973) and Shaw (1973). Schumpeter (1934) emphasized the importance of financial services for promoting economic growth, and highlighted the conditions under which financial institutions could promote innovation to accelerate economic growth, through efficient management of funding of productive activities (Chow and Fung, 2011; Pradhan et al., 2015; Pradhan et al., 2017; Uddin et al., 2014; Wolde-Rufael, 2009). However, financial resources misallocation and excessively speculative activities was considered by some authors as casting doubt on expectations of financial development to stimulate economic growth (Adeniyi et al., 2015; Cheng et al., 2021; Opoku et al., 2019; Rousseau and Wachtel, 2000; Samargandi et al., 2015; Sassi and Goaied, 2013). However, financial development seems to have regained its prominence as an engine of economic growth and a catalyst of other factors of production including energy. Three hypotheses have been proposed concerning the nexus between financial development, energy consumption, pollution and promotion of the energy transition. The first predicts the negative influence of the financial sector related to environmental damage based on funding of projects which create short-term value for shareholders, regardless of the induced medium or long term negative consequences for the environment, and the financing of conventional sources of energy. C Competition in

financial markets can induce amnesia related to environmental priorities (Assi et al., 2021; Boutabba, 2014; Destek and Sarkodie, 2019; Riti et al., 2017). The second hypothesis is related to the effect of the financial sector on the development of renewable energies and promotion of energy efficiency. This hypothesis predicts a positive role financial development by promoting innovation and R&D which have a positive impact on economic development and growth and reduce the negative impacts on the environment (Ali et al., 2018; Eren et al.. 2019; Khan et al., 2021; Shahbaz et al., 2013). The third hypothesis predicts that financial development has a limited or even null effect on environmental degradation (Acaravci and Ozturk, 2012; Dogan and Turkekul, 2016; Iorember et al., 2020).

The third stream of work focuses on the nexus between ICT and economic growth. ICT have been touted as a major global competitiveness factor based on their interaction with all sectors of activity and their influence on productivity, and thus economic growth. Numerous empirical studies (Cheng et al., 2021; Colecchia and Schreyer, 2002; Das et al., 2018; Fernandez-Portillo et al., 2020; Oliner and Sichel, 2000; Pradhan et al., 2017; Sassi and Goaied, 2013; Skorupinska and Torrent-Sellens, 2017) acknowledge the positive effects of ICT at the micro and macroeconomic levels. However, some authors find negative effects (Acemoglu et al., 2014; Albiman and Sulong, 2017; Arvanitis and Loukis, 2009; Bresnahan et al., 2002; Haller and Lyons, 2015; Thompson and Garbacz, 2011). Therefore, this mixed empirical evidence on economic growth suggests we need further analysis of the influence (or not) of ICT adoption on energy conservation and the energy transition. Some studies suggest an essential role for ICT in facilitating this transition and reducing emissions in a range of sectors from energy management, to construction and teleworking, without the need for technological disruption (Azam et al., 2021; Sadorsky, 2012; Salahuddin and Alam, 2016; Solarin et al., 2019). For example, the application of industry 4.0 technologies (big data, collaborative robotics, cloud computing, integration of simulation systems, 3D printing, additive manufacturing,

cybersecurity, Internet of Things, virtual and augmented reality) with electric mobility and smart grids associated with ICT contributes to reducing production, logistics, maintenance and total energy consumption costs, and promoting innovation in new renewable or at least less polluting sources of energy (Gobbo et al., 2018). At the same time, some researchers point that the ICT sector as being among the most polluting and energy intensive (Irawan, 2014; Moyer and Hughes, 2012; Ozcan and Apergis, 2018; Sahoo et al., 2021).

3. Methodology

3.1. Data and preliminary analysis

The data used for the empirical analyses were extracted from two sources: the World Bank Development Indicators (WDI), and the US Energy Information Administration (EIA) database. Table 1 presents the data, their sources and some descriptive statistics. Our analysis includes 11 MENA economies (Algeria, Egypt, Iran, Iraq, Jordan, Lebanon, Mauritania, Morocco, Syria, Tunisia, and Turkey) selected on the basis of data availability which we study over the period 1980 to 2018.

Table 1. Variables' definition and descriptive statistics

Variable	Description	Obs.	Mean	Std. Dev.	Min.	Max.	Source
LGDP_PC	GDP per capita: The ratio between gross domestic product (constant 2010 US$) and population	429	8,087	0,544	7,006	9,628	WDI
LGFCF_PC	GFCF per capita: The ratio between gross fixed capital formation (constant 2010 US$) and population	429	6,553	0,727	3,163	8,378	WDI

LNREC_PC	The ratio between total energy consumption (except renewables) and population (mtoe/person)	429	-0,208	0,638	-2,310	1,271	EIA
LREC_PC	The ratio between energy consumption from renewables and population (mtoe /person)	429	-3,995	1,304	-7,730	-1,289	EIA
LICT	Information and communication technologies index: average of fixed telephone subscriptions (per 100 people), mobile cellular subscriptions (per 100 people), and individuals using the Internet (% of population)	429	2,012	1,509	-1,555	4,275	WDI
LFD	Financial development: The ratio between domestic credit to private sector and GDP (% of the GDP)	429	3,188	1,091	0,237	4,667	WDI

Note: Variables are log-transformed.

3.2. Model construction

To estimate our model to explain the effect on economic growth of energy, ICT and financial development, we draw on Solow's (1956) neoclassical growth model augmented by Mankiw et al. (1992), and specify a Cobb-Douglas function production as follows:

$$Y_{it} = A_t \prod_{k=1}^{K} X_{kit}^{\alpha_k} \quad \text{avec} \quad 0 < \alpha_k < 1 \tag{1.1}$$

where Y_{it} is gross domestic product (GDP), X_{it} is the vector of our explanatory variables, A_t is technological progress and α_k are elasticities.

We apply the natural logarithm to rewrite the linearized equation as follows:

$$Ln(Y_{it}) = Ln(A_t) + \sum_{k=1}^{K} \alpha_k Ln(X_{kit}) \quad (1.2)$$

where ***i*** is 11 cross-sections, ***t*** is the time period and ***k*** is the five explanatory variables.

3.3. Econometric methodology

To empirically examine the impact on economic growth (*LGDP_PC*) of renewable energy (*NREC_PC*), non-renewable energy (*LNREC_PC*), ICT (*LICT*) and financial development (*LFD*) in the presence of investment (*LGFCF_PC*), we employ advanced econometric procedures. We follow the usual steps: first, we assume that the homogeneity of the slopes will be tested, and second that cross section dependence (CD) in panel will be checked; third, we assume that having verified the stationarity properties of the variables, a panel cointegration test will be conducted. Finally, the choice of econometric model and estimation approach will be based on the results of the previous tests allowing an analysis of the long-run causal relationships between the variables.

3.3.1. Test for slope homogeneity

The choice of the model estimation method using panel data is based on identification of the nature of the slopes. To test the homogeneity of the slopes, we use the Pesaran and Yamagata (2008) test which is based on dispersion of each individual weighted slope. Monte-Carlo simulations show that the test is appropriate for small sample sizes and dynamic and unbalanced panel data. The empirical model is expressed by the following equations:

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}\right)$$

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{\frac{2k(T-k-1)}{T+1}}}\right)$$

3.3.2. Test for cross-section dependence

The aim of the CD test is run to verify the existence of potential common correlation effects on our variables. Ignoring CD in panel data can affect the estimation results (Baltagi et al., 2007). In our case, the CD test is used to We want to check whether the individual variables are dependent that is to verify cross-section dependence. Pesaran's (2015) CD test outperforms other tests due to its applicability to different variable lengths. The test is given by the following equation:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{ij}\right)$$

3.3.3. Panel unit-root test

The next step consists of testing the order of integration of the different variables. Pesaran's (2015) CD test shows the existence of cross section dependence for all the variables implying possibly biased results from a first-generation unit root test (Dogan and Seker, 2016). We take account of cross-sectional dependence of errors and slope heterogeneity and apply the second-generation panel unit root test (Pesaran's, 2003 CADF, and Pesaran's, 2007 CIPS). According to Baltagi et al. (2007) the CIPS test is more robust in the presence of various sources of cross-sectional dependence, including spatial or geographical proximity. The CADF is given by the following equation:

$$\Delta Z_{it} = \phi_i + \varsigma_i Z_{i,t-1} + \sigma_i \overline{Z}_{t-1} + \sum_{j=0}^{p}\sigma_{ij}\Delta\overline{Z}_{t-1} + \sum_{j=1}^{p}\lambda_{ij}\Delta Z_{i,t-1} + \varepsilon_{it}$$

where, $\overline{Z}_{t-1}$ and $\Delta\overline{Z}_{t-1}$ are averages for the lagged and first differences of each cross-section series.

CIPS statistics are derived from the CADF as follows:

$$CIPS = \frac{1}{N}\sum_{i=1}^{n} CADF_i$$

3.3.4. Panel cointegration test

Use of cointegration tests is widespread in econometrics. Their objective is to test for the existence or not of a linear combination between the stationary variables in levels and in first differences. Examining cointegration makes it possible to test for the existence of a long-term equilibrium relationship among the variables considered. There are several cointegration tests; first, those used to test the cointegration of time series; second, those applied to panel data which include two groups of cointegration tests to determine the existence of a long-term equilibrium relationship between the variables.

The first set of cointegration tests known as first-generation panel cointegration tests, includes the tests developed by Kao (1999) and Pedroni (1999, 2001, 2004) which address the problem of heterogeneity among different panel members. Pedroni (2004) developed seven cointegration test statistics, of which four are considered pooled tests (within dimension) and three are considered group mean tests (across dimensions). However, these tests ignore cross-sectional dependence in panel analyses.

The second group of cointegration tests account for possible cross-section dependence in the data. Westerlund (2007) developed four panel cointegration tests based on an error correction model (ECM) which considers all possible interindividual dependencies. In this study, we test for the existence of a long-term equilibrium relationship among the variables using the Westerlund (2007) and Pedroni (2004) tests.

3.3.5. Model specification

Using the above theoretical framework, analysis of effect of our explanatory variables on economic growth is carried out using the CS-ARDL modeling approach. The nature of our data requires estimation of a dynamic model in the presence of common correlated effects (CCE) and cross section dependence as proposed by Chudik et al. (2016) and developed further by

Ditzen (2018). This model takes account of unobservable common factors that might affect countries. Similar to a dynamic model the lagged dependent variable is not strictly exogenous, and Pesaran's (2006) CCE approach to estimate panel models in the presence of transverse dependence becomes inconsistent. Chudik et al. (2016) show that the estimator is more consistent if a delay is added to the cross-section means used in the estimation. Thus equation (2) is rewritten as:

$$LGDP\_PC_{it} = \alpha_0 + \sum_{j=1}^{P} \beta_{it} LGDP\_PC_{i,t-j} + \sum_{j=0}^{P} \alpha_{it} X_{t-j} + \sum_{j=0}^{3} \phi_{it} \bar{Z}_{t-j} + \varepsilon_{it} \qquad (1.3)$$

with,

$\bar{Z}_t = (\Delta\overline{LGDP\_PC_t}, \bar{X}_t')'$ and

$X_{it} = (LGFCF\_PC_{it}, LNREC\_PC_{it}, LREC\_PC_{it}, LICT_{it}, LFD_{it})'$.

3.3.6. Dumitrescu and Hurlin causality test

Finally, we test for causality using bivariate regression in a panel data frame. ***t* is** the dimension of the period and ***i is*** dimension of the cross section in a panel dataset. Therefore, the bivariate regressions are:

$$y_{it} = \rho_{0,i} + \rho_{1,i} y_{i,t-1} + ... + \rho_{k,i} y_{i,t-k} + \delta_{1,i} x_{i,t-1} + ... + \delta_{k,i} x_{i,t-k} + \upsilon_{i,t}$$
$$x_{it} = \rho_{0,i} + \rho_{1,i} x_{i,t-1} + ... + \rho_{k,i} x_{i,t-k} + \delta_{1,i} y_{i,t-1} + ... + \delta_{k,i} y_{i,t-k} + \upsilon_{i,t}$$

To estimate panel data causalities, we adopt the Granger non-causality approach (Dumitrescu and Hurlin, 2012). The standard Granger test assumes that all the coefficients are similar for all the individuals in the panel. The test developed by Dumitrescu and Hurlin (2012), assumes that the coefficients differ based on the cross sections.

Thus, the power of traditional causality testing can be enhanced by combining time series information with cross-section data. This takes account of country heterogeneity due to

economic, political, structural or institutional particularities. The test estimates individual Granger causality for each cross section, and calculates the average of the individual tests considering a statistical significance ($\overline{W}$ statistical) and a standardized statistic $\overline{W}$, called the $\overline{Z}$ statistic. In this case, the null hypothesis is: ***y*** does not homogeneously cause ***x***, and vice versa.

4. Results and discussion

We test the slope homogeneity hypothesis using Pesaran and Yamagata's (2008) test. Table 2 shows that the null hypothesis of slope homogeneity is rejected in all cases since probability values are less than 0.01. Thus, we need to consider the presence of heterogeneity in the panel data and can deduce that the model coefficients are heterogeneous and that slopes vary from country to country. We therefore need to apply heterogeneous panel techniques.

Table 2. Slope Homogeneity Test (Pesaran and Yamagata, 2008)

Slope Homogeneity Tests	Δ statistic	p value
$\tilde{\Delta}$ test	14.620***	0.000
$\tilde{\Delta}_{adj}$ test	16.140***	0.000

The null hypothesis for slope heterogeneity test is slope coefficients are homogenous. *** denote significant at 1% level.

Table 3 presents the results of Pesaran's (2015) cross-dependency test and show the existence of cross-section dependence for all the variables in the panel data. In other words, there is a dependency factor between countries meaning that a shock to one country can cause a ripple effect and transmission to other countries. This suggests the need for a second-generation unit root test.

Table 3. Pesaran (2015) test for weak cross-sectional dependence

Pesaran (2015) test for weak cross-sectional dependence		
Variables (in log)	**CD-Statistic**	**P-value**
GDP per capita (LGDP_PC)	46.294***	0.000
Gross fixed capital formation per capita (LGFCF_PC)	46.123***	0.000
Renewable energy consumption (LREC_PC)	36.237***	0.000
Non-renewable energy consumption (LNREC_PC)	43.891***	0.000
Information and communication technologies (LICT)	41.966***	0.000
Financial development (LFD)	43.373***	0.000

Notes: The CD statistic is normally distributed under the null hypothesis of no cross-sectional dependence. *** denote significant at 1% level.

Table 4 presents the results of the CIPS and CADF tests in levels and in first differences. The results indicate that the variables *LGFCF*_PC and *LICT* are stationary in level, that is, I(0) and that the variables *LGDP_PC*, *LREC_PC*, *LNREC_PC* and *LFD* are stationary in first difference, that is, I(1).

Table 4. Results of panel unit-root

Variables	**Level**		**First-difference**		**Order**
(in log)	**Without trend**	**With trend**	**Without trend**	**With trend**	
Cross-Sectionally Augmented IPS (CIPS)					
LGDP_PC	-2.055***	-2.655***	-5.256***	-5.267***	I(1)
LGFCF_PC	-2.207**	-2.844***	-5.029***	-5.068***	I(0)
LREC_PC	-2.141**	-2.616*	-5.962***	-6.172***	I(1)
LNREC_PC	-1.877	-2.502	-5.646***	-5.741***	I(1)
ICT	-2.366***	-3.314***	-5.356***	-5.358***	I(0)
FD	-1.811	-2.579*	-5.359***	-5.640***	I(1)

Cross-Sectionally Augmented Dicky-Fuller (CADF)

LGDP_PC	-2.264**	-2.533	-3.238***	-3.293***	I(1)
LGFCF_PC	-2.524***	-3.019***	-3.498***	-3.580***	I(0)
LREC_PC	-1.933	-2.139	-3.420***	-3.821***	I(1)
LNREC_PC	-1.501	-1.990	-3.408***	-3.355***	I(1)
LICT	-2.286**	-3.230***	-3.382***	-3.339***	I(0)
LFD	-1.753	-2.606	-2.991***	-2.983***	I(1)

Notes: The panel unit-root test was performed under the null hypothesis wherein the variables are homogeneous non-stationary. ***, **, and * denote statistical significance level at 1%, 5%, and 10%, respectively.

Table 6 presents the results for the Westerlund (2007) cointegration test using data for 11 MENA countries for all the variables. The advantage of this method is that it works well in the presence of heterogeneous slope coefficients and dependence among individual data in the panel. The null hypothesis assumes that there is no long-term cointegration among the variables; the alternative hypothesis assumes the opposite.

The results of the Westerlund (2007) test show that the statistics lead to rejection of the hypothesis of non-cointegration at panel level rather than at the individual level. Also, the results of Pedroni's (2004) test (table 5) indicate that the null hypothesis of no cointegration is rejected for six of the seven statistics. We therefore need to estimate the long-term equilibrium relationships among the variables.

Table 5. Pedroni (2004) panel cointegration test

Tests	**Within-dimension**		**Between-dimension**	
	Statistic	**P-values**	**Statistic**	**P-value**
ν-statistic	-0.4915	0.311		
ρ-statistic	-3.852***	0.003	-2.864**	0.002

PP- statistic	-12.300***	0.000	-13.63***	0.000
ADF- statistic	-9.961***	0.000	-10.28***	0.000

Notes: All test statistics are is normally distributed under a null hypothesis of no cointegration. ***, ** denote significant at 1% and 5% level, respectively.

Table 6. Westerlund (2007) Panel cointegration tests

Statistic	**Value**	**Z-value**	**P-value**
Gt	-3.624***	-4.647	0.000
Ga	-16.437**	-2.036	0.021
Pt	-12.106***	-4.800	0.000
Pa	-18.773***	-4.480	0.000

Notes: The Gt and Ga statistics test co-integration for each cross-section, and Pt and Pa test cointegration in the panel under the null hypothesis of no cointegration. ***, ** denote statistical significance level at 1% and 5%, respectively.

Table 7 presents the results of the CS-ARDL model for the short term (upper rows) and long term (lower rows) relation. Before discussing the coefficients of the estimations, note that the CD test cannot reject the null hypothesis of weak cross-section dependence which suggests that the results in table 7 are not biased by the presence of cross-section dependence.

The results show that as expected the coefficient of the error correction (ECT) is negative and significant (-0.12, p=0.000). Thus, the ECT provides no evidence rejecting cointegration. Also, the long-run results based on the CS-ARDL estimator suggest that per capita output is positively and significantly related to gross fixed capital formation, energy consumption and ICT and that 1% increase in LGFCF_PC, LNREC_PC, LREC_PC and LICT, ceteris paribus, stimulates LGDP_PC by 0.081%, 0.225%, 0.018%, 0.050% respectively. The estimated coefficient of financial development is negative and significant at the 1% level, implying that a 1% improvement in financial development reduces LGDP_PC by 0.116%. This is in line with

previous studies including Adeniyi et al. (2015), Barajas et al. (2011); Cheng et al. (2021), Kenza and Salah Eddine (2016), Samargandi et al. (2015) and Sassi and Goaied (2013).

The empirical results show that the extent of the impact of non-renewable energy on economic growth in the MENA region is 12.5 times higher than the impact of renewable energy. Thus, the positive impacts of renewable and non-renewable energies on economic growth have important policy implications and suggest that that MENA economies should focus on the energy to ensure energy security and benefit from the positive impact on long-run growth. The MENA countries should focus their investments primarily on renewable energies and assess the effects of phasing out us of fossil fuels in sectors such as electricity, transport and industry. Several countries will face particularly severe due mainly to lack of investment. These countries will continue to be heavily dependent on petroleum resources; the reorientation of support for renewable energy producers to increase the share of renewable energy in the total energy mix is far from automatic. Experience from around the world shows that successful development of renewable energies requires a stable political, regulatory and legal environment to attract more foreign and domestic investment, support mechanisms, reduction of fossil fuel subsidies, and incentives related to simpler administrative processes and sanctioning of inefficient energy use.

We show also that financial development is related negatively to economic growth which is perhaps explained by financial sector weakness, lack of competition in banking systems, misallocation of financial resources, macroeconomic volatility and financial crises, or the existence of non-linear relationships.

Our estimation results reveal a positive and statistically significant influence of ICT on GDP. This is in line with Cheng et al. (2021), Das et al. (2018), Fernandez-Portillo et al. (2020), Pradhan et al. (2017) and Sassi and Goaied (2013) who recognized the positive effects of ICT diffusion on economic growth. However, if ICT are considered to be general-purpose technologies (Helpman and Trajtenberg, 1998) this suggests that the MENA countries will have

to invest in ICT to achieve their full potential for supporting economic growth and to mitigate the negative effects of financial development on economic growth. Financial sector developments need to be reinforced by ICT infrastructure, greater Internet penetration and further integration of electronic finance policies. ICT will also play an important part in promoting renewable energy, improving energy efficiency, fighting climate change and facilitating the energy transition by contributing to advances in energy research to reduce production, logistics and maintenance costs.

It should be noted that the short-run results of the CS-ARDL are similar in both magnitude and sign to the long-run results.

Table 7. CS-ARDL panel data estimation results

	Coefficient	**Std. Err.**	**Z-statistics**	**P-value**
Short-run results				
ECT	-0.120***	0.070	-16.02	0.000
LGFCF_PC	0.088***	0.021	4.21	0.000
ΔLNREC_PC	0.273**	0.111	2.46	0.014
ΔLREC_PC	0.020***	0.007	2.92	0.004
LICT	0.062*	0.034	1.83	0.068
ΔLFD	-0.126***	0.038	-3.30	0.001
Long-run results				
LGFCF_PC	0.081***	0.019	4.20	0.000
LNREC_PC	0.225**	0.095	2.37	0.018
LREC_PC	0.018***	0.006	3.16	0.002
LICT	0.050*	0.030	1.68	0.093
LFD	-0.116***	0.036	-3.25	0.001

CD Statistic	-1.16		0.244
Root MSE	0.06		

Notes: The CD statistic test is standard normally distributed under the null of hypothesis of weak cross-sectional dependence. ***, **, and * denote statistical significance level at 1%, 5%, and 10%, respectively.

Robustness: alternative method

To test the robustness of the results of the CS-ARDL model (Table 7), we conducted some sensitivity checks. First, we estimated the common correlated effect mean group (CCEMG) model developed by Pesaran (2006) which allows the variables to be heterogenous in the long run. Second, since the CS-ARDL estimate does not provide any information on the causal links between the variables we employ Dumitrescu and Hurlin's (2012) causality test.

CCEMG panel data model

The results of the CCEMG robustness test are presented in table 8 and confirm that our findings from the CS-ARDL are robust and show that with the exception of the coefficient of LFD which is negative and significant all the other coefficients are positive and significant under the CCEMG estimator.

Table 8. CCEMG panel data estimation results

	Coefficient	**Std. Err.**	**Z-statistics**	**P-value**
Dependent variable (LGDP_PC)				
LGFCF_PC	0.052***	0.013	3.89	0.000
ΔLNREC_PC	0.034**	0.016	2.09	0.037
ΔLREC_PC	0.026***	0.010	2.65	0.008
LICT	0.298***	0.084	3.55	0.000
ΔLFD	-0.103**	0.041	-2.50	0.013

Const.	-0.018	0.330	-0.05	0.957
CD Statistic	-0.231			0.817
Root MSE	0.056			

Notes: The CD statistic test is standard normally distributed under the null of hypothesis of weak cross-sectional dependence. ***, ** denote statistical significance level at 1% and 5%, respectively.

Dumitrescu and Hurlin causality test

Table 9 summarizes the results of the Dumitrescue-Hurlin Granger causality test. They show affirms that the results of the causality test are consistent with the results of the panel CS-ARDL estimator.

We find seven bidirectional causal relationships between: LGDP_PC ↔ LNREC_PC, LGDP_PC ↔ LREC_PC, LGDP_PC ↔ LICT, LGDP_PC ↔ LFD, LICT ↔ LNREC_PC, LICT ↔ LREC_PC and LFD ↔ LREC_PC, and evidence of three unidirectional causal relationships: LNREC_PC → LREC_PC, LNREC_PC → LFD and LFD → LICT.

Table 9. Dumitrescu and Hurlin (2012) Granger non-causality tests

Null Hypothesis	**W-bar**	**Z-bar**	**P-value**
LNREC_PC does not Granger-cause LGDP_PC	2.224	2.456	0.014
LGDP_PC does not Granger-cause LNREC_PC	2.995	4.085	0.000
LREC_PC does not Granger-cause LGDP_PC	1.999	1.980	0.048
LGDP_PC does not Granger-cause LREC_PC	3.562	5.282	0.000
LICT does not Granger-cause LGDP_PC	2.141	2.282	0.023
LGDP_PC does not Granger-cause LICT	3.464	5.074	0.000
LFD does not Granger-cause LGDP_PC	2.098	2.189	0.029
LGDP_PC does not Granger-cause LFD	2.647	3.350	0.001

LREC_PC does not Granger-cause LNREC_PC	1.961	1.901	0.057
LNREC_PC does not Granger-cause LREC_PC	3.039	4.176	0.000
LICT does not Granger-cause LNREC_PC	3.297	4.722	0.000
LNREC_PC does not Granger-cause LICT	3.381	4.900	0.000
LFD does not Granger-cause LNREC_PC	1.314	0.536	0.592
LNREC_PC does not Granger-cause LFD	3.484	5.117	0.000
LICT does not Granger-cause LREC_PC	4.553	7.374	0.000
LREC_PC does not Granger-cause LICT	4.141	6.503	0.000
LFD does not Granger-cause LREC_PC	3.015	4.127	0.000
LREC_PC does not Granger-cause LFD	3.802	5.788	0.000
LFD does not Granger-cause LICT	4.755	7.800	0.000
LICT does not Granger-cause LFD	1.940	1.856	0.064

5. Conclusion and policy implications

We set out to investigate the dynamic relationship between ICT diffusion, financial development, energy consumption and economic growth building on the studies by Cheng et al. (2021), Das et al. (2018), Fernandez-Portillo et al. (2020), Pradhan et al. (2017), Sassi and Goaied (2013) and Solarin et al. (2019) which consider development of renewable energies and diffusion of ICT as relevant variables to boost economic activity, create jobs and improve environmental quality.

We provide three main findings which have some important policy implications.

First, we found a positive impact of renewable and non-renewable energies on economic growth, suggesting that the MENA economies should focus on the energy sector to ensure their energy security. The MENA countries should support energy innovations, new energy

infrastructures and regulation in order to increase use of renewable energies. They should invest in R&D, increased human capital and a modern energy infrastructure to achieve a successful energy transition. The future will depend on good management of the energy sector and progress in the deployment of renewable energies. Accelerating the deployment of renewable energies and strengthening energy efficiency would allow the MENA countries to reduce their energy deficit and control public finances.

Second, financial development is related negatively to economic growth. The reasons for this negative relationship are many and include financial sector weaknesses, macroeconomic volatility, financial crises and non-linear relationships. A stronger financial system could produce greater financial stability and a sustainable financial sector will be key to economic growth in the MENA countries. It would facilitate trade and investment, allow the monitoring of risk and promote savings to fund projects. Financial innovations should be encouraged and carefully managed. Financial inclusion and financial integration should be promoted in the MENA countries to foster economic growth.

Third, we found a positive and statistically significant influence of ICT on GDP meaning that MENA countries should continue to invest in ICT to achieve their full potential to support economic growth. The MENA countries should strengthen their digital infrastructures and implement new technologies. Implementation of new organizational practice models driven by adoption of new digital technologies must be prioritized by MENA country firms. Workforces should be trained in order to have the required e-skills to perform jobs in the future. Reducing digital divide must also be a priority since digital inclusion fosters economic development and growth.

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