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The Role of Entrepreneurial Activities, ICT and Energy Consumption in the Economic Growth: An Econometric Evidence of EU Countries

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ABSTRACT

The objective of the study to develop the linkages between economic growth (GDP), energy consumption, information and communication technology (ICT), and total entrepreneurial activities (TEA) in 17 European Union countries over the period 2000-2023. Annual data were analyzed using co-integration tests such as Fisher, Kao, Westerlund, and Pedroni to determine the long-term relationship among the variables. The study also employed PMG to examine the long-run elasticities, as well as DOLS and DMOLS for robustness. The results indicated that increased entrepreneurial activities, energy consumption, and ICT lead to growth in GDP in the EU region. This means that in the current situation, entrepreneurial activities strongly contribute to robust economic growth, which may result in developing sustainable, stable and progressive societies/economies. Furthermore, the study noted bidirectional causality running between the considered variables.

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1. Introduction

The key area for every state-economy or regional economy is to understand and dig out the factors contribute towards attainment of development and economic growth. Conventionally, the neoclassical model of economic growth (Solow-Swan, 1956) emphases on investments in human capital. However, the theory of endogenous growth (Romer, 1986) clinch the notion regarding role of knowledge oriented factors. Entrepreneurship is seen as an endogenous element of the neoclassical model that drives economic growth. The impact of the Covid-19 pandemic on national economies has garnered the attention of scholars and policymakers to promote entrepreneurship as creation of new companies is essential to re-launch the economies of affected countries (Adeel et al., 2023). Achieving economic development through entrepreneurship (Daniel et al., 2021) has been broadly predictable as a central component for economies, society, organizations and industry. Throughout history, entrepreneurial efforts have played a pivotal role in advancing innovation, which in turn has stimulated industrial growth, generated employment opportunities, and enhanced both economic progress and societal welfare (Audretsch et al., 2007). Though, different studies have showed contradictory outcomes regarding the influence of entrepreneurship to macroeconomic environment and economic growth (Stoica et al., 2020b). The relationship between energy consumption and economic growth has been investigated in the literature by several researchers (Apergis & Payne, 2010). Another by Ewing et al. (2007) showed that production has significantly impacts economic growth and energy consumption effects it negatively.

Recent advances limbed the growing relevance of digital infrastructure, energy efficiency, and entrepreneurship in shaping economic resilience particularly within the EU, where digital and institutional disparities remain distinct. Countries with strong ICT integration and innovation policies commonly experience sustained growth and adaptability (Magoutas et al., 2024).

Entrepreneurship has not only been linked with GDP growth but also enhancing R&D and transformation of knowledge (Peris-Ortiz et al., 2018). Moreover, many researcher reveals that energy from renewable sources plays a significant role in sustainable growth (Ntanos et al., 2018). ICT related energy innovations help in reducing consumption inefficiencies and improve integration among the sectors ultimately results in productivity and environmental performance (Hu et al., 2022). This study aims to address the gap in existing literature regarding the relationship between entrepreneurial activities and environmental degradation. Additionally, new macroeconomic variables are introduced to assess environmental quality in EU countries. The study employs both traditional and state-of-the-art panel econometric techniques and utilizes updated data to provide the most recent findings to aid decision-makers in the EU. The analysis is conducted using panel data from 17 European countries from 2000 to 2023, selected based on data availability. By examining the combined effects of total entrepreneurial activity (TEA), energy consumption, and ICT on economic growth, this research provides a comprehensive perspective on how innovation, technology, and resource utilization interact in shaping long-term development. The use of robust empirical methods, including co-integration tests, PMG estimation, and causality analysis, ensures the reliability of results.

2. Literature Review

2.1. The relationship between GDP and ICT

Information communication technology (ICT) has been considered as an important parameter of economic growth in last two decades. According to Mayer et al. (2020), "comparative research presents inconsistent findings regarding how strongly ICT is linked to economic growth." It is broadly recognized in empirical literature claims economic growth is influenced by multiple factors (Scarpetta et al., 2005). Madden and Savage (1998) showed that there is significantly positive relationship between the GDP and ICT investments using data for 27 European countries from 1990 to 1995. Farhadi and Ismail (2012) also confirmed the positive impact of this relationship in various industrial sectors of the economy. Expanding on this, recent literature focusing specifically on EU countries and reveals several additional dimensions to this relationship. Alfaro Cortés and Alfaro Navarro (2011) analyzed ICT's influence on both human development and GDP in the EU-27. They found that ICT implementation led to significant differences in economic outcomes between clusters of EU countries, depending on the degree of ICT penetration. Magoutas et al. (2024) found a strong positive link between ICT development particularly in advanced technologies like AI and GDP growth in the EU, using data from the Digital Economy and Society Index. Their study underscores ICT’s role in driving not just economic performance but also digital transformation in both business and government sectors. Similarly, Fernández-Portillo et al. (2020), using PLS-SEM on OECD EU countries, showed that stronger ICT infrastructure corresponds with more robust economic outcomes, suggesting that closing digital gaps could mitigate regional disparities. Laitsou et al. (2017) further demonstrated ICT's resilience during the Eurozone crisis, identifying it as the only input with a consistently positive effect on GDP.

2.2. The relationship between GDP and TEA

The connection between entrepreneurship and economic growth has gained attention in numerous studies, as found in the existing literature (Acs et al., 2012; Carree & Thurik, 2008; Urbano & Aparicio, 2016; Valliere & Peterson, 2009). Some authors (Carree et al., 2002; Wennekers et al., 2005) have discovered inverse nonlinear linkage between entrepreneurship and GDP while focusing on various countries' economic development. Empirical studies by Urbano & Aparicio (2016) support these findings, while reporting different levels of entrepreneurship capital on GDP in 43 countries from 2002 to 2012. Moreover, Stoica et al. (2020a) found that entrepreneurial activity has a positive and significant impact on economic growth in all OECD countries and reporting a greater impact. Meanwhile, Doran et al. (2018) demonstrated a notable impact of entrepreneurial activities on GDP in developed countries as compare to developing countries. The authors also suggest that the type of entrepreneurship also affects its impact on economic growth. In addition, some authors, on the one hand, argued that opportunity-based entrepreneurship and high expectation entrepreneurship have the highest impact on economic growth in developed countries, whereas, necessity-based entrepreneurship has the least impact. On the other hand, high-expectation entrepreneurship and necessity-based entrepreneurship have the largest impact on GDP in developing countries, while opportunity-based entrepreneurship has the lowest impact. Additionally, Abdinnour & Adeniji (2023) used panel data from GEM countries (2001–2021) to analyze both short- and long-term effects of TEA on GDP. The findings of the study indicate that while the short-term effect of TEA is normally weak

or negative, however, continuous entrepreneurial efforts produce positive impacts on economic growth. Peris-Ortiz et al. (2018) further add that TEA not only influences GDP, but also innovation, R&D, industry-university collaboration, and digital knowledge transformation.

2.3. The relationship between Energy Demand and GDP

Global warming has intensified concerns about the environmental costs of economic growth, particularly the heavy reliance on fossil fuels for energy. To promote long-term sustainability, a shift toward renewable energy is essential. Kaygusuz et al. (2007) emphasize that renewables can alleviate the energy crisis while advancing sustainable development. However, as Mehrara (2007) showed, the connection between GDP growth and energy consumption is complex and context-dependent, with empirical findings varying by country, method, and timeframe. Since the energy crises of 1947 and 1981, scholars have debated this nexus, yielding mixed conclusions due to methodological and regional differences (Erol & Yu, 1987; Masih & Masih, 1996; Belke et al., 2011). Nevertheless, renewable energy is increasingly recognized as a strategic response to these challenges. Chien and Hu (2007) argue that renewables improve macroeconomic efficiency, and optimizing energy use remains vital for sustainable growth. Recent EU-based studies provide deeper insights. Streimikiene and Kasperowicz (2016) found that energy use, capital formation, and employment are positively influence long-run GDP growth over 18 EU countries. Andrei (2024) observed signs of decoupling in the EU-27, where some economies continue to grow despite declining per capita energy use though this varies by state. Ntanos et al. (2018) reported that in higher-income European nations, renewable energy consumption is more strongly correlated with GDP growth. Similarly, Caraiani et al. (2015) identified bidirectional causality between energy use and economic output in emerging European markets.

3. Methodology

3.1. Model

The research model is formulated as follows:

$$EconomicGrowth = f(\,Energy, TotalEnterprenurialActivities\,, ICT)$$

Amri (2018) assessed economic growth using per capita GDP, while ICT was assessed based on mobile and landline subscriptions per 100 individuals, along with total entrepreneurial activity across EU countries. Entrepreneurial activity was used as an indicator of a nation's level of economic development.

3.2. Data

This study utilizes annual data from 2000 to 2023 for 17 European countries, selected based on data availability from WDI and GEM

3.3. Methodology

The study employs a range of econometric techniques to analyze data from 17 EU countries between 2000 and 2023. Descriptive statistics and correlation analysis provide initial insights into variable relationships. To address cross-sectional dependence, the Pesaran (2021) CD test and Breusch-Pagan LM test were applied. Unit root properties were examined using both first- and second-generation tests (W-stat, ADF-Fisher, PP-Fisher), followed by cointegration analysis via Pedroni (2004) and Westerlund (2007) methods. Long- and short-run dynamics were estimated using the Pooled Mean Group (PMG) approach, with FMOLS and DOLS used for robustness checks. Lastly, the Dumitrescu-Hurlin causality test was conducted to explore directional relationships across the panel.

4. Results

Table 1 reports the descriptive statistics and correlation outcomes for the European countries. Cross-sectional dependence was assessed using the LM and CD tests, with Table 2 indicating strong dependence across units.

Table 1: Descriptive and Correlation Analysis

Variables	LENERGY	LGDP	LICT	LTEA
Mean	9.014570	10.57235	5.025452	1.719513
Std. Dev.	0.618695	0.498641	0.138390	0.323915
Maximum	10.91143	11.42481	5.291434	2.430978
Minimum	8.004123	9.298059	4.384728	0.488580
LENERGY	1			
LGDP	0.5812	1		
LICT	0.2064	0.4293	1	
LTEA	0.1225	0.1174	0.0914	1

Table 2: Results of CD and Breusch-Pagan LM tests

Test/Variables	LENERGY	LGDP	LICT	LTEA
Pesaran CD	15.67[a] (0.00)	37.03 [a] (0.00)	33.50 [a] (0.00)	10.86 [a] (0.00)
Breusch-Pagan LM	691.13 [a] (0.00)	100.39 [a] (0.00)	1278.69 [a] (0.00)	394.37 [a] (0.00)

Note: [a] represents the 1% significance level and P-values reported in the small parenthesis.

Arshad et al. (2020) suggested that the ADF test may not be enough to detect unit roots. To address this issue, second-generation unit root tests applied other than ADF test. Table 3 presents the results, indicating that most of the variables are non-stationary at their original level. However, after tasking first differences, the variables are stationary, accepting the null hypothesis with level of 5% significance. These findings demonstrate the panel unit roots of the variables.

Table 3: Results of Unit Root test

Variables	Levin, Lin & Chu t*	Im, Pesaran and Shin W-stat	ADF - Fisher	PP - Fisher
LENERGY	1.2193 (0.8886)	2.1916 (0.9858)	24.2042 (0.8931)	48.5606 (0.0504)
∆LENERGY	-2.5819[a] (0.0049)	-3.0938[a] (0.0010)	62.5013[a] (0.0021)	166.95[a] (0.000)
LICT	-7.0069[a] (0.0000)	-4.5673[a] (0.0000)	85.8137[a] (0.0000)	268.044[a] (0.0000)
∆ LICT	-4.004[a] (0.0000)	-2.2591[a] (0.0000)	49.7126[a] (0.0000)	81.7012[a] (0.0000)
LTEA	0.00344 (0.5014)	-0.8843 (0.1883)	45.98[b] (0.0823)	72.4898[a] (0.0001)
∆ LTEA	-10.2184[a] (0.0000)	-11.4797[a] (0.0000)	180.564[a] (0.0000)	524.37[a] (0.0000)
LGDP	-1.3729[c] (0.0849)	0.94386 (0.8274)	22.9790 (0.9241)	17.4468 (0.9916)
∆ LGDP	-7.7046[a] (0.0000)	-2.2949[a] (0.0000)	87.5554[a] (0.0000)	109.100[a] (0.0000)

Diverse co-integration tests were applied. Furthermore, as the data exhibit cross-sectional dependence, the test by Westerlund (2007) was also applied, as it is considered the most suitable for handling cross-sectional dependence. All the results are presented in Tabe 4.

Table 4: Cointegration

Pedroni Test				Kao Residual Cointegration Test		
		Statistic	Weighted Stat	ADF	T-Stat	Prob
Within – dimension	Panel v	0.7215 (0.22)	-0.2822 (0.63)		-4.231045[a]	0.0000
	Panel rho	-0.5826 (0.28)	-0.1986 (0.43)	Johansen Fisher Panel Cointegration Test		

	Panel PP	-4.2189 [a] (0.00)	-4.2634 [a] (0.00)	**No Cointegration**	**of**	**Trace**	**Max eigen test**
	Panel ADF	-2.2965 [a] (0.01)	-3.7051 [a] (0.00)	None		176.9[a] (0.0000)	176.9[a] (0.0000)
Between-dimension	Group rho	0.2920 (0.61)		At most 1		316.9[a] (0.0000)	258.5[a] (0.0000)
	Group PP	-4.8940 [a] (0.00)		At most 2		120.3[a] (0.0000)	94.27[a] (0.0000)
	Group ADF	-3.1126 [a] (0.01)		At most 3		82.02[a] (0.0000)	82.02[a] (0.0000)
Westerlund Cointegration							
Statistics	**Value**	**Z-value**	**P-value**	**Statistics**	**value**	**Z-value**	**P-value**
Gt	-7.058	-8.873	0.00[a]	Pt	-10.489	-3.617	0.00 [a]
Ga	-3.952	3.573	1.00	Pa	-5.679	2.182	0.98

Table 5: Estimation results of the long-run relationship between economic growth, energy consumption, , ICT, and entrepreneurial activities

Methods	**PMG**		**FMOLS**		**DOLS**	
Variables	**Coefficient**	**Prob**	**Coefficient**	**Prob**	**Coefficient**	**Prob**
Long-run coefficients						
LENERGY	1.4089[a]	0.0000	0.137144[a]	0.0012	0.115970[b]	0.0243
LICT	0.5586[a]	0.0000	0.285034[a]	0.0000	0.253368[a]	0.0000
LTEA	0.3220[a]	0.0000	0.039287[a]	0.0081	0.041655[c]	0.0628
Error correction coefficients	-0.0664[a]	0.0730				
Short-run coefficients						
D(LENERGY)	0.3863[a]	0.0000				
D(ICT)	0.1516[b]	0.0128				
D(LTEA)	-0.0047	0.5788				
C	-0.3491[c]	0.0791				

The results of all four co-integration tests unanimously agreed to take the alternative hypothesis, suggesting that all the underlying countries will change together within long period. The results of the pooled mean regression group, as presented in Table 5, reveal a strong and sustained correlation between entrepreneurship, ICT adoption, and energy consumption with economic growth. This indicates that they all move together in the long run. The results confirmed a long-term impact of exogenous variables on the outcome variable as ECT was significantly negative (i.e., -0.06), indicating a speed of adjustment toward equilibrium of 6% per year. The results also reported significant short-term associations, as shown in Table 5. The robustness of the PMG estimates was added to confirmed including FMOLS and DOLS methods, which generated analogous results in terms of coefficient signs.

Table 6: Causality

Null Hypothesis:	**W-Stat.**	**Z bar-Stat.**	**Prob.**	**Causality**
LENERGY does not homogeneously cause LGDP	1.47308	-1.27915	0.2008	ENERGY— GDP
LGDP does not homogeneously cause LENERGY	4.93144	2.05471	0.0399	GDP→ENERGY
LICT does not homogeneously cause LGDP	2.37624	-0.05797	0.9538	ICT— GDP
LGDP does not homogeneously cause LICT	3.92821	2.08111	0.0374	GDP→ICT
LTEA does not homogeneously cause LGDP	1.67872	-1.01174	0.3117	TEA— GDP
LGDP does not homogeneously cause LTEA	4.86226	3.45383	0.0006	GDP→TEA
LICT does not homogeneously cause LENERGY	6.82240	3.87760	0.0001	ICT↔ENERGY
LENERGY does not homogeneously cause LICT	4.79020	1.91856	0.0550	
LTEA does not homogeneously cause LENERGY	2.28453	-0.49691	0.6193	TEA— ENERGY
LENERGY does not homogeneously cause LTEA	6.23459	3.31095	0.0009	ENERGY→TEA
LTEA does not homogeneously cause LICT	5.35560	4.04848	0.0000	TEA↔ICT
LICT does not homogeneously cause LTEA	5.26118	3.91834	0.0000	

In table 6, column fourth is showing the causality relationship direction for each variable .

5. Discussions

The findings reveal a positive linkage between entrepreneurial activity, ICT, and energy consumption. Park et al. (2018) noted that when panel data is drawn from countries with varying institutional contexts, cultural norms, and national characteristics, cross-sectional dependence (CD) is likely, potentially leading to biased estimates. Similar concerns were raised by Kebede et

al. (2010) in their analysis of African nations. Tvaronaviciene (2016) further emphasized that the relationship between entrepreneurship and energy use may be influenced by security challenges and argued that sustainable long-term linkages require active participation from both individuals and institutions in energy management. Similar to entrepreneurship, ICT during the last two decades has drastically increased energy consumption, especially for electricity (Usman et al., 2021). Asian economies are among the top emitters of CO_2 and other pollution sources and must emphasize reducing energy use through technological innovation, thereby recommending energy efficiency (Xinmin et al., 2020). These outcomes have forced policy-makers and implementers to consider various perspectives.

Our findings are in line with Madden and Savage (1998), who investigated a significant positive correlation between GDP and ICT in a study of 27 European countries from 1990 to 1995. This suggests that increased investment in ICT can boost economic growth, providing nations with competitive benefit within the global market. Jorgenson & Vu (2005) and Farhadi & Ismail (2012) also confirmed the positive relationship between ICT and GDP. Elgin (2013) highlighted the impact of ICT on the economy from 1999 to 2007 using panel data from approximately 152 countries, confirming it as a major predictor and influencer of GDP. Several studies, including panel data studies (Salahuddin et al., 2016) and (Sadorsky, 2012;), have inspected the linkages of energy consumption over ICT over the years. Ishida (2015) explored the long-standing correlation among energy consumption, ICT, and GDP growth over three decades. To support the reliability of the results, the analysis employed first- and second-generation unit root tests. Other than detecting such dependencies, advanced estimation techniques were applied to improve accuracy. The findings suggest that while energy use and digital infrastructure influence growth in the short run, entrepreneurial activity play a more sustained role in long-term development. The analysis also revealed significant unidirectional causal links from GDP to energy use, ICT, and entrepreneurship, as well as from energy consumption to entrepreneurship. Additionally, two-way causality identified in ICT and energy use, and also in ICT and entrepreneurial activity. However, no significant causality was observed between GDP and any of the other variables when considered in reverse, nor between entrepreneurship and energy use. Given the increasing role of technologies in improving productivity and reducing resource consumption, the results point toward several policy directions. Digital transformation through e-commerce, remote work, and virtual collaboration has led to notable savings in time and energy. Policymakers in the EU should prioritize investment in renewable energy over conventional sources and encourage environmentally responsible practices, including green innovation and higher taxation on polluting activities. Furthermore, facilitating access to financing for aspiring entrepreneurs especially recent graduates can foster inclusive economic participation.

6. Conclusion

This study explored the long-term relationship between GDP, ICT, energy consumption, and total entrepreneurial activity (TEA) across EU countries from 2000 to 2023. Co-integration techniques including Westerlund, Fisher, Kao, and Pedroni tests were employed to assess long-run associations, while the PMG estimators was used to investigate elasticities. Robustness was confirmed through DOLS and DMOLS models. Findings reveal that TEA, along with ICT development and energy use, positively influences (GDP) economic growth in the EU, with evidence of bidirectional causality among the variables. Entrepreneurship plays a broader role in addressing societal and global challenges through innovation. As Zahra and Wright (2016) suggest, entrepreneurial solutions are increasingly tackling issues like resource scarcity and environmental degradation. For sustained growth, EU governments should further promote eco-friendly policies by integrating clean energy initiatives with ICT advancements.

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