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The Impact of ICT Usage on Energy Consumption Efficiency and Environmental Sustainability in Developing Countries: An Empirical Analysis

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ABSTRACT

This study examines the impact of Information and Communication Technologies on energy consumption, energy efficiency, CO_2 emissions, and renewable energy adoption in developing countries using the time span of 2007 to 2019 has been used. The results of Generalized Method of Moments reveal that ICT has a multifaceted impact on energy dynamics in developing countries. With increase in ICT adoption, energy consumption increase in developing countrues. Moreover, increase in usage increases CO_2 emissions. We find that increase in oil prices encourages the adoption of energy-efficient technologies and reduce CO_2 emissions. In constrats, we find limited effect of ICT on renewable energy mainly due to infrastructural barriers in developing countries.

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1. Introduction

The objective of this paper is to investigate the impact of Information and Communication Technologies (ICTs) usage on energy consumption, energy efficiency, carbon emissions and renewable energy adoption in developing economies. The global economy has seen extraordinary growth in technology since the start of 20^{th} century compared to the preceding centuries (F. Ahmed, Naeem, & Iqbal, 2017). The potential advantages and the use of ICTs are widely acknowledged (Niebel, 2018). However, the growing trends in ICT usage, energy consumption, and climate change are becoming key areas of concern in the contemporary global world (Sustainable Development Goals, 2016). ICTs are broadly implemented to boost the global economic competitiveness, productivity, growth, innovation, and efficiency. By reducing the manufacturing and travel time, it effectively improves human lives through electronic commerce, e-governance, e-health, and online learning opportunities (Ngwenyama, Andoh-Baidoo, Bollou, & Morawczynski, 2006). The term "global village" is coined because of enhanced global communication made possible through ICT adoption but as the communication technologies are widely utilized, they exert an impact on energy consumption (Salahuddin & Alam, 2015). Vast literature covers the inter-relationships amongst ICTs, energy consumption, environmental quality, energy efficiency and renewable energy Mahdavi and Sojoodi (2021); Murshed (2020), However, to the best of our knowledge, there is no evidence on these relationships for the case of developing countries. There are several reasons to evaluate these relationships for developing economies. First, the increased dependency of human lives on technology has increased energy demand. There will be a 37 percent (an average annual increase of 1.4 percent) increase in global energy demand during 2013 to 2035 (BP Energy Outlook, 2035). Moreover, energy consumption has significantly increased due to accessibility and cost reduction in ICTs. Majority of purchases and business transactions can now be done electronically or online, resulting in a significant reduction in the demand for physical transportation as about 4.54 billion individuals globally use the internet regularly (Australian Internet Statistics, 2023). Compared to 87% of the individuals in affluent countries, 47 percent of people in developing nations have an internet connection (International

Telecommunication Unit 2019). The reduction of gaps in the ICT usage trends among developed and developing economies is indicated by increased ICT penetration and acceptance.

Second, structural issues have exacerbated energy shortages in developing countries due to widespread inefficiencies causing energy losses in production, distribution, and consumption. Inadequate maintenance and poor fuel quality reduce power plant reliability. Outdated and poorly maintained distribution systems waste energy and the lack of investment prevents the replacement of outdated industrial equipment. Huge population uses inefficient heating sources like raw coal and wood. Hence, ICTs can successfully enhance energy efficiency by integrating businesses and processes through modeling, analysis, monitoring and visualization tools that can make the best use of already available physical resources while taking into consideration a variety of factors that affect energy demand (Stallo, De Sanctis, Ruggieri, Bisio, & Marchese, 2010). Third, because of increase in incomes, globalization and industrialization, energy consumption is rising at an accelerated rate (Xie, Liu, Chen, & Wang, 2018). Fossil fuels are being exploited to meet this rising demand for energy (Azam, Rafiq, Shafique, & Yuan, 2022). The burning of fossil fuels is the biggest contributor to climate change due to emission of greenhouse gases (Azam, Rafiq, Shafique, Zhang, & Yuan, 2021; Chaudhry, Safdar, & Farooq, 2012). The population in the low-income countries still relies on conventional biomass and fossil fuels at the lower rungs of the energy ladder (Ai, Du, Li, Li, & Liao, 2021). Fourth, transition to renewable energy (RET) is seen as a viable strategy for reducing the amount of environmental pollutants released through the burning of nonrenewable energy resources (Sharif, Mishra, Sinha, Jiao, Shahbaz, & Afshan, 2020). Nowadays, renewable energy sources provide about 29% of the global electricity. Global economy aims to increase renewable energy-based electricity generation by 2050. However, one of the main factors impeding RET possibilities in developing economies is the technological challenges faced by developing countries (K. H. Nguyen & Kakinaka, 2019). Technological redundancy discourages low-income economies from adopting RET (Fashina, Mundu, Akiyode, Abdullah, Sanni, & Ounyesiga, 2018). Lack of technological development makes it challenging to store energy generated by renewable sources, making it challenging to include RE in the energy mix (J. Lu, Ren, Yao, Rong, Skare, & Streimikis, 2020). Products and services associated with ICTs can help in integrating RE resources in the existing energy mix and can be utilized to create renewable energy or to support their production process. The literature on impact of ICTs illustrates following research gaps. The nature of existing research is subjective, explanatory Houghton (2015); Yi and Thomas (2007) while empirical analysis mainly considers the case of developed economies (Salahuddin, Alam, & Ozturk, 2016). Thus, this pursues the following research objectives. First, we assess the impact of ICT usage on energy consumption in low- and middle-income countries and evaluate how the adoption of ICTs affects the efficiency of energy utilization. Second, we ascertain the influence of ICT usage on CO_2 emissions and empirically estimate the impact of ICT usage on RET for the case of developing economies.

2. Review of Literature

Literature highlights a two-way effect of ICT use on energy use. The use of energy increases from production, distribution, and usage of ICTs due to their ease of use and cost reduction. All appliances and communication tools with which people access, transmit, or retain information are incorporated under ICT (Pradhan, Mallik, & Bagchi, 2018). Salahuddin and Alam (2015) found the positive effect of internet usage on electricity consumption in Australia. K. Ahmed and Ozturk (2018) discovered that long-term usage of cutting-edge technologies could boost China's energy consumption by 0.4%. Saidi, Toumi, and Zaidi (2017) found positive effect of ICT on electricity use in 67 different nations. Sadorsky (2012) supported the finding that rising economies' energy consumption is an outcome of the use of ICTs. Takase and Murota (2004) found that there is a direct impact of IT investments on CO_2 emissions and energy usage in the US but found a negative relationship for Japan. The findings of Schulte, Welsch, and Rexhäuser (2016) provide credence to the hypothesis that ICTs can significantly contribute to energy conservation. Han, Wang, Ding, and Han (2016) assessed ICT use in China and found to have a considerable negative influence on the nation's short-term energy consumption. Ishida (2015) performed a three-decade (1980–2010) analysis for Japan to analyze the long-term association among technology, energy use and economic growth. ICT investments were found to have a modest decrease in energy consumption (Bastida, Cohen, Kollmann, Moya, & Reichl, 2019).

Malmodin and Lundén (2018) revealed that IT sector has largely reduced the tendency of carbon footprints to increase. Continued improvements in the ICT sector reduce energy usage and CO2 emission. Ponce-Jara, Ruiz, Gil, Sancristóbal, Pérez-Molina, and Castro (2017) reflected that smart grids have many beneficial effects in developed as well as developing nations, including decreased energy theft and losses in nations like Brazil and India. Global economy is facing primary sustainability challenges in the form of increased CO_2 emissions having welfare consequences (Ben-Jebli et al., 2016). The significance of ICT for ecology and environmental challenges is emphasized by the works of Houghton (2015); Yi and Thomas (2007) but these studies lack empirical analysis. Lashkarizadeh and Salatin (2012) used data from 43 industrialized and emerging nations to analyze the relationship between ICTs and environmental deterioration. Ozcan and Apergis (2018) revealed the negative impact of ICTs on air pollution. Tsaurai and Chimbo (2019) demonstrated that investment in ICTs helped the emerging markets' air quality to improve. Al-Mulali, Sheau-Ting, and Ozturk (2015) found little effect of online retailing carbon emissions. W.-C. Lu (2018) showed that ICTs significantly increased CO_2 emissions in 12 Asian economies between 2000 and 2013. These studies have a narrow scope as they used "internet use" as a proxy for ICTs only and have a small sample size. Opponents proclaim that ICT expansion has increased carbon emissions and reduced air quality (Belkhir & Elmeligi, 2018; Salahuddin, Alam, & Ozturk, 2016). Danish, Khan, Baloch, Saud, and Fatima (2018) found that ICTs contribute in CO_2 emissions in 20 emerging economies. ICTs usage has direct and indirect effects on sustainability Haseeb, Xia, Saud, Ahmad, and Khurshid (2019) as it optimizes manufacturing processes, increases energy efficiency, develops transportation infrastructure, decreases emission intensity and creates smarter towns. The growth in ICTs sector supports CO_2 emissions reduction (Akande, Cabral, & Casteleyn, 2019).

ICTs are higher in demand and supply as the economy expands, placing pressure on the amount of energy required (Dabbous, 2018). One of the major factors contributing to the investment in CO_2 emissions is the consumption and production of energy. It implies that the use, development and disposal of ICTs have detrimental effects on the environment. F. Ahmed, Naeem, and Iqbal (2017) examined the role of ICTs in making the world more environmentally sustainable, specifically through utilizing renewable energy sources and making other technologies smarter. It facilitates the creation of creative business plans that enhance energy access and delivery while fostering the consumption of renewable energy D. Wang and Han (2016), such as the installation of mini-grids and real-time monitoring and control to assist the management of elements like erratic wind speed, sun radiation, and water movement. Cahill (2022) analyzed expansion of Ukraine's production of renewable energy which improved energy security. Consuming energy from renewable sources can be enhanced by employing innovation. Geng and Ji (2016) revealed a continuous, reciprocal causal link between renewable energy and technical innovation. This review of literature indicated that there is a strong association among ICT, energy consumption, energy efficiency, environmental sustainability and renewable energy transition. ICT use has altered consumer behavior, increased the efficiency of various tasks and helped society and industry in saving energy (Yan et al. 2018). By Decrease in electricity and energy demand, consumers have increased energy efficiency Schulte, Welsch, and Rexhäuser (2016) which has reduced carbon emissions (W.-C. Lu, 2018). Furthermore, through promotion of renewable energy, there will be an indirect effect on the environment. Increased public awareness towards renewable energy use and harmful effects of fossil fuel consumption is an outcome of ICT use (Ajayi & Ohijeagbon, 2017).

3. Research Methodology

3.1. Data and data Sources

This study uses the World Bank classification for developed and developing countries. Based on the availability of data, 52 developing countries have been selected for the time span of 2007 to 2019. The list of variables and summary statistics are presented in table 1.

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
ICT	1.409	2.335	0.0010	16.159
Energy Consumption	0.714	1.499	0.0016	9.356
Energy intensity	5.510	2.561	1.33	16.34
CO_2 Emissions	0.975	1.188	0.021	7.137

Renewable energy transition	52.482	27.00	0.06	95.29
Crude Oil Prices	496.92	145.07	275.04	702.29
Inflation	8.765	15.35	0.0296	225.39
Net Official Development Assistance (NODA)	0.091	0.888	-0.668	5.5125
Exports	26.36	68.23	0.0382	538.63
Foreign Direct Investment (FDI)	2.38	5.89	0.00056	50.55
GDP per capita	1888.53	1185.98	170.71	5610.73
Imports	30.249	76.619	0.1902	640.30
Personal Remittances	4.504	10.307	0.0002	83.332
Total Observations	676			

3.2. Generalized Method of Moments

To evaluate the relationship between ICTs, overall energy consumption, energy intensity, CO_2 emissions, and the transition towards renewable energy, we have utilized a dynamic panel data modeling approach. Even in the presence of endogeneity, this approach removes the unbiased dynamic nature of the relationships. The generalized method of moments (GMM) approach is employed to address the issue of endogeneity using instrumental factors which mitigate the bias associated with small sample sizes. GMM can be appropriately applied when T < N (13 < 52). This study uses system GMM because it improves the efficiency of estimates (Roodman, 2009, 2020; Windmeijer, 2005). The frequent use of Windmeijer (2005) bias correction process in literature is due to its dealing with the heteroscedasticity problem. The extension to Arellano and Bond (1995) presented by Roodman (2009) limits the over identification problem associated with the instruments.

3.2. Model Specification

This study modified the empirical model of Murshed (2020) to measure the impact of ICT on energy consumption, energy intensity and environmental sustainability in developing countries. The dynamic panel data modelling has been adopted following (Mirza, Ansar, Ullah, & Maqsood, 2020). The econometric model used in the study are as follows:

I. Total Energy Consumption Model

$$lnTEC_{it}=\theta_0+\theta_1 lnTEC_{i,t-\tau}+\theta_2 lnICT_{i,t}+\sum^5_{h=1}\delta_h W_{h,i,t-\tau}+n_i+\varepsilon_t+\mu_{it} \quad (1)$$

$$lnTEC_{it}-lnTEC_{i,t-\tau}=\theta_0+\theta_1(lnTEC_{i,t-\tau}-lnTEC_{i,t-2\tau})+\theta_2(lnICT_{i,t}-lnICT_{i,t-\tau})+\sum^5_{h=1}\delta_h(W_{h,i,t-\tau}W_{h,i,t-2\tau})+(\varepsilon_t-\varepsilon_{t-1})+n_i+\mu_t 1b$$

II. Energy Intensity Model

$$lnEI_{it}= \gamma_0+ \gamma_1 lnEI_{i,t-\tau}+ \gamma_2 ICT_{i,t}+ \sum^4_{h=1} \delta_h W_{h,i,t-\tau} +n_i + \varepsilon_t+ \mu_{it} \quad (2)$$

$$lnEI_{it}-lnEI_{i,t-\tau}= \gamma_0+ \gamma_1(lnEI_{i,t-\tau}-lnEI_{i,t-2\tau})+ \gamma_2(lnICT_{i,t}-lnICT_{i,t-\tau})+\sum^4_{h=1}\delta_h(W_{h,i,t-\tau}-W_{h,i,t-2\tau})+(\varepsilon_t-\varepsilon_{t-1})+n_i+\mu_{it}$$

III. Environmental Sustainability Model

$$lnCO_{2it}=a_0+a_1 lnCO_{2i,t-\tau}+a_2 lnFTS_{it}+\sum^5_{h=1}\delta_h W_{h,i,t-\tau}+n_i+\varepsilon_t+\mu_{it} \quad (3)$$

$$lnCO_{2it}-lnCO_{2i,t-\tau}=a_0+a_1(lnCO_{2i,t-\tau}-lnCO_{2i,t-2\tau})+a_2(lnICT_{it}-lnICT_{i,t-\tau})+\sum^5_{h=1}\delta_h(W_{h,i,t-\tau}-W_{h,i,t-2\tau})+(\varepsilon_t-\varepsilon_{t-1})+n_i+\mu_{it}$$

IV. Renewable Energy Transition Model

$$lnRET_{i,t}= \delta_0+ \delta_1 lnRET_{i,t-\tau} +\delta_1 lnICT_{i,t}+\sum^5_{h=1} \delta_h W_{h,i,t-\tau} +n_i + \varepsilon_t+ \mu_{i,} \quad (4)$$

$$lnRET_{it} -lnRET_{i,t-\tau}= a_0+ a_1(lnRET_{i,t-\tau} - lnRET_{i,t-2\tau})+ a_2(lnICT_{it}-lnICT_{i,t-\tau})+\sum^5_{h=1} \delta_h (W_{h,i,t-\tau}-W_{h,i,t-2\tau})+ (\varepsilon_t - \varepsilon_{t-1})+n_i + \mu_{i,t}$$

Where $lnTEC_{it}$ reflects the log of total energy consumption, $lnTEC_{i,t-\tau}$ is the lag of total energy consumption, FTS represents the fixed telephone subscriptions used as a proxy for measuring ICT usage. W corresponds to the control variables including crude oil prices (COP), inflation (INF), net inflows of foreign direct investment (FDI), net official development assistance (NODA), GDP per capita (GDPPC) and personal remittances (PR). $lnEI_{i,t}$ represents the log of energy intensity, $lnEI_{i,t-\tau}$ is the lagged value of energy intensity. W encompasses the control variables of FDI, per capita GDP and personal remittances (PR). $\ln CO_{2it}$ is logarithmically transformed metric to capture CO_2 emissions in percentage terms. $\ln CO_{2i,t-\tau}$ is refers to the lagged value of CO_2 emissions. W shows the control variables; namely, COP, net inflow of foreign direct investment (FDI), GDPPC, imports (IMP) and personal remittances (PR). ε_t represents time-specific effects, n_i captures country-specific effects, and μ_{it} denotes the standard error term. RET_{it} represents the logarithm of the renewable energy consumption. $\ln RET_{it-\tau}$ represents the lagged value of $\ln RET_{it}$. Control variables in equation (4) under W, are crude oil prices (COP), inflation (INF), net inflow of FDI, GDPPC, NODA, exports(EXP), imports (IMP) and personal remittances (PR). This study uses the Sargan test for over-identification to verify the reliability of instruments which allows to test the null hypothesis that over-identifying restrictions are valid. The rejection of null hypothesis reveals that instruments are not correlated with error term. The Arellano Bond test has been used to test the null hypothesis of no autocorrelation. For accurate model specification, The AR(1) test should be significant while AR(2) should be insignificant to confirm the validity of the instruments.

4. Results and Discussion

Table 2 presents the results from GMM estimations. The results of Model 1 indicate that past energy consumption has statistically significant impact on current energy consumption (see table 2). ICTs increase energy consumption which is similar to (Sadorsky, 2012). In an effort to catch up technologically, developing nations might adopt more energy-intensive technology, thus increasing energy consumption. Limited resources and infrastructure hinder energy-efficient tech implementation, further contributing to energy use. Increase in the crude oil prices decreases the total energy consumption significantly at 5% significance level. Higher crude oil prices incentivize the adoption of indigenous and cost-effective alternative energy sources. Developing countries meet a large portion of their energy needs by improting oil and thus the increase in crude oil prices increases the import cost burden forces them to reduce overall energy consumption. These results are consistent with (A. T. Nguyen, 2022). The coefficient of Inflation shows a positive effect on energy consumption. Increased production costs including energy prompt businesses to raise prices, leading to higher energy consumption. In response to rising prices, individuals might engage in "hoarding," increasing consumption of goods, including energy-related ones, to hedge against further price hikes.

Increase in net official development assistance increases the total energy consumption significantly. ODA initiatives enhance the access to modern energy in underserved communities which increases energy consumption. The percentage increase in FDI increases energy consumption significantly conforming with (Amoako & Insaidoo, 2021). FDI involves investments in infrastructure to enhance productivity and economic development. Results suggest that increase in GDP per capita has a direct but statistically insignificant impact on total energy consumption (see table 2, model 1). Developing countries often have diverse economic structures, with some sectors being more energy-intensive than others. As GDP per capita rises, the composition of the economy may shift towards less energy-intensive sectors, moderating the overall increase in energy consumption. Personal Remittances increase can lead to a significantly higher increase in total energy consumption (See table 2) as these stimulate economic activity, raise living standards, and facilitate infrastructure development in recipient countries, all of which typically entail increased energy consumption across various sectors of the economy.

Model 2 indicates that increase in lagged energy intensity increases current energy intensity by 0.801 percent. Increased use of ICT has significantly reduced energy intensity (see table 2). These results are consistent with (Zhao, Hafeez, & Faisal, 2022). The absence of a significant relationship among developing countries is due to the difficulty in building and sustaining a strong ICTs infrastructure and using the full potential of energy-efficient technology and procedures. ICTs adoption in underdeveloped nations is still in its early phases due to which there is a lack of integration into diverse industries and hence, a negligible impact on total energy efficiency. The insignificant impact of FDI on energy intensity is supported by the fact that FDI encompasses a wide range of activities across different sectors and industries. Some FDI projects worsen the level of energy intensity (investments in energy-intensive manufacturing), while others promote energy efficiency (investments in renewable energy technology). The net effect may be positive but statistically insignificant due to the variability in FDI activities. GDP per capita has a statistically significant negative relationship with energy intensity (see table 2). Results from model 2 are in line with results from Zhou, Yin, and Yue (2023). Greater investments in technology and innovation are stimulated by higher GDP per capita resulting in energy-efficient practices and reduced energy intensity through transition to renewable energy technologies.

Table 2: Regression Results

	Model 1	**Model 2**	**Model 3**	**Model 4**
	Energy Consumption	Energy Intensity	Environmental Sustainability: CO_2 emissions	Renewable Energy transition
Total Energy Consumption (Log) (-1)	0.1311 (2.23)			
Log of Energy intensity (-1)		0.8009 (8.08)		
Log of CO_2 emissions(-1)			0.8864 (19.69)	
Renewable energy transition (-1)				0.9959 (54.13)
ICT (Log)	0.1431 (1.79)	0.00023 (-0.07)	0.0280 (2.40)	0.0036 (0.69)
Crude Oil Prices (Log)	-0.2696 (-2.17)		-0.0390 (-1.91)	
Inflation (Log)	0.0960 (2.30)			
Net Official Development Assistance (Log)	0.3089 (2.23)			0.0026 (0.45)
Exports (in log)				0.01917 (2.03)
Log of Foreign Direct Investment	0.2686 (2.79)	0.00633 (1.62)	0.0061 (1.26)	0.0006 (0.02)
Log of GDP per Capita	0.2585 (1.31)	-0.0443 (-2.05)	0.0818 (2.18)	-0.0155 (-1.27)
Imports (log)			0.0166 (1.95)	-0.0226 (-1.98)
Remittances (Log)	0.3256 (3.61)	-0.0085 (-2.05)	0.0057 (-1.07)	
Constant	*-20.488* *(-3.71)*	*0.6857* *(2.12)*	*-0.7977* *(-2.11)*	*0.1427* *(0.78)*
AR(1)	*-3.20* *(0.001)*	*-3.50* *(0.00)*	*-3.83* *(0.00)*	*-3.05* *(0.002)*
AR(2)	*0.84* *(0.402)*	*0.07* *(0.948)*	*0.12* *(0.902)*	*-0.67* *(0.505)*
Sargan Test	*2.48* *(0.480)*	*9.49* *(0.148)*	*5.18* *(0.269)*	*3.26* *(0.353)*
Hansen Test	*0.84* *(0.499)*	*5.37* *(0.497)*	*1.79* *(0.774)*	*5.46* *(0.141)*
Observations	*624*	*624*	*624*	*617*
Countries	*52*			
Instruments	*12*	*12*	*12*	*11*

** z-values in brackets.*

Personal remittances have a significant negative relation with energy intensity at the 5% significance level. Remittances frequently help in diversifying economies by giving people a boost in income. Households make investments in energy-saving appliances, house improvements, and other energy-saving strategies as their financial situation improves. Model 3 results finds that CO_2 emissions in the past have a positive impact on the current CO_2 emissions (See table 2). Increased ICT usage leads to statistically significant increase in CO_2 emissions at a 5% significance level. Danish et al. (2018) found that ICTs have a significantly positive impact on CO_2 emissions in developing economies. Model 3 in table 2 shows the negative effect of Crude oil prices CO_2 emissions. Increased oil prices lead to reduced demand and usage of crude oil, hence, a decline in CO_2 emissions. The prospect of higher oil prices encourages the adoption of energy-efficient technologies and practices along with cleaner and alternative energy sources. Industries and consumers are motivated to invest in energy-saving measures, which can drive down overall energy use and result in reduced CO_2 emissions. Increase in FDI increases CO_2 emissions insignificantly at a 5 percent significance level. The results are consistent with Huang, Chen, Wei, Xiang, Xu, and Akram (2022). Similar to Cederborg and Snöbohm (2016), we find significant effect of GDP per capita on CO_2 emissions in developing countries (see table 2). Increase in imports significantly increases CO_2 emissions (see table 2). Najibullah, Iqbal, Nosheen, Khan, Raja, and Jasim (2021) found similar results for G7 countries. Developing countries heavily rely on energy-intensive industries like manufacturing, mining, and construction for economic growth. Importing raw materials and finished goods for these sectors leads to increased CO_2 emissions due to less efficient and more carbon-intensive production processes. The fossil fuel dependence for energy production and transportation further raises emissions, as imports of these fuels contribute to CO_2 emissions during extraction, refining, transportation, and consumption.

Consistent with Khan, Rafique, Ullah, and Khan (2022), table 2 shows positive but insignificant impact of personal remittances on CO_2 emissions. Remittances might not influence industries with high pollution levels, leading to a lack of changes in production processes or investment in polluting sectors. Environmental policy gaps, weak enforcement, and limited environmental awareness might hinder the potential of remittances to curb pollution. Remittances might be prioritized for immediate needs, rather than longer-term investments that could lead to substantial pollution reduction. If environmental concerns are not prioritized, remittances might not result in significant changes in purchasing patterns that effectively reduce pollution. Results from Model 4 suggest that past energy transition levels strongly influence current renewable energy adoption. The impact of ICT on renewable energy transition is minimal, as a 1% increase in ICT increases renewable energy adoption only by a slight and statistically insignificant increase of 0.0036%. ICT might not have a meaningful influence on renewable energy transition conforming with results of Geng and Ji (2016). Many developing countries face challenges in terms of ICT infrastructure, including limited access to reliable internet connectivity and technological resources. Without a robust ICT foundation, the potential benefits of ICT for renewable energy may not be fully realized. The existence of a digital divide in developing countries, with disparities in access to technology and digital literacy hinders the effective adoption of ICT tools and limit their impact on renewable energy transition. Table 2 shows that Net ODA is the primary driver of the changes in renewable energy transition. Other factors like domestic policies, technological capacity, market conditions, and geopolitical considerations also influence the pace of renewable energy adoption. This result is consistent with (Q. Wang, Guo, & Dong, 2021). However, the impact of ODA on the growth of renewable energy was adverse when the urbanization and carbon dioxide emission levels are above the threshold. This shows that the ODA does not always attract renewable energy consumption. Conversely, the ODA would impede the development of renewable energy when technological advancement and societal structure change reach a certain point.

Increase in exports significantly increases the renewable energy transition conforming with the results of Sharma, Shahbaz, Kautish, and Vo (2021). The economic incentives attained through exports can support transition towards renewable energy. A positive but insignificant relationship between FDI and renewable energy transition is consistent with Nadia and Seema (2016). Actual FDI investment might not be targeted towards adoption of renewable energy and can be concentrated in other sectors. Limited FDI flows into renewable energy projects results in an insignificant impact on renewable energy transition. A significantly negative impact of imports on renewable energy transition conforms with Xie et al. (2018). Limited financial resources in developing countries lead to trade-offs between investing in renewable energy and importing fossil fuels. If countries prioritize meeting immediate energy demands through fossil fuel imports, it delays investments in renewable energy infrastructure and technologies. Increase in GDP per capita reduces renewable energy transition (see table 2) which conforms with Ergun, Owusu, and Rivas (2019). The developing countries prioritize investments in traditional energy infrastructure as their income increases due to their perceived economic benefits and existing industrial capabilities. This results in diversion of resources from renewable energy projects. The insignificant value of AR (2) in all models reveals that the problem of autocorrelation does not exist in our estimates. Likewise, insignificant value of Sargan and Hansen tests indicate instruments used in the analysis are valid.

5. Conclusion and Policy Recommendations

This study examines interrelationships between ICTs, energy consumption, energy efficiency, CO_2 emissions, and renewable energy in 52 developing countries from 2007 to 2019. We find that ICT, energy use in previous years, inflation and NODA has a significant effect on current total energy consumption, whereas crude oil prices negatively associated with energy consumption. Lagged value of energy intensity and FDI enhaced energy intensity in current time, while increase in ICTs usage, GDP per capita and remittances decrease energy intensity for these economies. Past carbon emissions, FDI, GDP per capita and imports have a direct effect on current level of carbon emissions in developing economies, whereas, ICTs use, crude oil prices affect carbon emissions negatively. Personal remittances show a mixed relationship with CO_2 emissions, with the impact varying across studies and factors such as economic diversification and environmental policies. In conclusion, the findings suggest a complex interplay between economic, technological, and environmental factors influencing energy consumption, energy efficiency, CO_2 emissions, and renewable energy transition.

Based on the findings, the study recommends policymakers to implement reforms aiming to encourage the use of energy-efficient practices in developing countries. Further, policymakers should ensure the easy provision of financial incentives and subsidies to encourage consumers and businesses to purchase energy-efficient machinery and appliances. Incentive-based regulations should be initiated to promote a smooth transition toward renewable energy sources. In addition, developing countries should encourage investment in R&D which will increase the affordability as well as efficacy of renewable energy technology. Such initiatives further help developing countries meet sustainable development targets. To foster collaboration between international organizations and developed economies, it is essential to facilitate the exchange of best practices and secure funding for environmental and sustainable energy initiatives. Developing countries should formulate long-term energy and environmental strategies that account for the complexities of trade, technology, and the global economy to ensure sustainable development. The successful implementation of these strategies requires tailoring policies to specific requirements of developing countries. Furthermore, policymakers should devise a robust system for monitoring and evaluating outcomes to enable continuous adaptation and improvement of these policies.

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