

Renewable Energy Consumption, Internet Adoption and Inclusive Growth in East Asia: A Linear and Nonlinear Investigation

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Abstract

Technological transformations are profoundly impacting every aspect of human life. Like every sector of the economy, technological advancements are reshaping industrial zones and altering the climatic conditions for a few decades. Therefore, this study scrutinizes the effects of renewable energy consumption, Internet adoption and financial development on inclusive growth in East Asia from 1995 to 2019. The current study utilizes novel approaches of panel ARDL and NARDL to explore the individual and joint effects of renewable energy and Internet adoption for inclusive growth and to compare their results. Moreover, the study contributes to the existing literature by using the newest multidimensional inclusiveness index to measure inclusive growth. The findings reveal that cleaner energy use, Internet access and financial development are significant determinants of inclusive growth. The increase and decrease in the combination of renewable energy and Internet adoption significantly enhance and reduce inclusive growth. The study confirms the nonlinear association between the cleaner energy-internet-growth nexus. The study recommends huge investments and microfinancing in the cleaner energy and digital sectors to reduce exclusions in poverty, inequality, and digital divide and attain inclusive growth.

Keywords: Digital Divide; East Asia; Nonlinear; Renewable Energy-Internet Adoption; Sustainable

JEL Classification: E24; F18; F64; G53

1. Introduction

Economic growth quantifies the overall development of an economy in terms of GDP while inclusive growth enumerates the speed of economic growth and distribution pattern of opportunities among the populace particularly for the marginalized people of society. Thus, economic growth accompanied by a reduction in inequalities, as well as promoting the participation of the masses in gainful employment refers to inclusive growth (Schoneveld, 2020). Therefore, most

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economists are of the view that the economic development process can be better described by inclusive growth rather than economic growth. The concept of inclusive growth has received special attention globally due to its broader nature since late 2000. While United Nations highlighted the importance of inclusive growth by including it in the 17 sustainable development goals (SDGs) in 2015. It lays the foundation for alteration in the course of action from focusing on economic development to accentuating growth for all.

The vital role of modern energy is recognized by the United Nations in Sustainable Development Goal 7 which emphasizes the provision of greener and inexpensive energy to everyone for attaining economic and environmental sustainability. The allied targets of SDG 7 integrated the provision of financial services to the majority population to facilitate access to cleaner energy. Renewable energy is a reliable source than non-renewable energy which enables the economies to get rid of heavy imported fuel bills and the depletion of natural resources. It does not emit carbon into the air thus abstains diseases and global warming. However, in comparison to developed economies, the developing and emerging economies are facing more difficulties with energy availability and energy security. Developing economies are also deficient in technical expertise and setup. They mostly depend on traditional energy resources like wood, coal, and natural gas to meet their energy needs so they are most vulnerable to the impacts of environmental change. Thus to avoid ecological hazards and to attain inclusive growth, it is mandatory to switch the needs of poor people towards renewable energy sources.

The efforts to attain inclusive growth under Vision 2030 are also very much related to introducing innovation and technological advancement (SDG 9). The neoclassical model highlights the importance of innovations with labor and capital as drivers of economic growth (Solow 1956). ICT has become a vital component of modern infrastructure, with widespread applications throughout world economies. ICT facilitates the industrial sector through online trading, mobile banking, rapid information and cashless transactions. ICT also improves facilities in the health, education and monetary sectors for all segments of society (Adeleye et al., 2020). Before 1990, the empirical evidence does not reveal a significant role of ICT in accelerating economic growth. Afterwards, many researchers find significant but mixed results of ICT on economic growth. Additionally, the existing literature proves that landlines, broadband, Internet and mobile telephony affect almost every sector of an economy directly or indirectly.

After viewing the current rapid adoption and revolutionary benefits of ICT all over the globe, this study aims to link the economic, ecological, technological

and financial framework for capturing their effects on inclusive growth. More specifically, this research contributes to the extant literature by examining the dynamic effects of renewable energy consumption, ICT adoption and financial development on inclusive growth rather than economic growth. In addition, the available literature on the interaction of ICT access and cleaner energy consumption towards the attainment of inclusive growth is very scarce and shows vague results. However, the significance of communication technology in developing the usage of cleaner energy among the masses cannot be ignored. ICT diffusion helps to yield and store solar and wind energies during peak times because these renewable energy sources are dependent on nature. Thus, ICT applications are contributing a lot towards curbing greenhouse emissions and enhancing renewable energy consumption in the total energy mix globally. Therefore, further research is needed to understand whether the combination of renewable energy and ICT has a linear or nonlinear association with inclusive growth in East Asia. This study also contributes to the literature by presenting a comparative analysis of the growth-energy-ICT nexus by employing the latest linear and nonlinear econometric approaches. Further, the use of novel proxies for inclusive growth and financial development in the case of East Asia also makes this research unique. The further arrangement of the study includes Section 2 comprises the review of some similar studies while the methodology of the empirical work is discussed in Section 3. The results, discussions and conclusion of the study are presented in Sections 4 and 5 respectively.

2. Literature Review

2.1 Renewable Energy Consumption and Inclusive Growth

The importance of the renewable energy sector has arisen a lot globally due to increasing economic and social hazards of greenhouse gases during the last few decades. The empirical investigations of (Shukla et al., 2017; Scherhoff and Sy 2017; Shahbaz et al., 2020 and Khan et al., 2020) highlighted the positive role of cleaner energy for economic growth in South Asia and Sub-Saharan Africa. Murshed (2018) analyzed the nonlinear connection between GDP and use of renewable energy in thirty-eight South Asian, Southeast Asian, Sub-Saharan African, Latin American and Caribbean Island economies from 2000-2014. These studies suggested global cooperation for research, development, production and provision of renewable energy products at a lesser cost to enhance the benefits of cleaner energy. While Charfeddine and Kahia (2019) stated that renewable energy consumption slightly increases economic growth in MENA countries. They laid the stress to conceive policies for elevating the consumption of cleaner energy by

households and firms efficiently. On the flip side, Ozcan and Ozturk (2019) established no association between renewable energy consumption and economic growth except for Poland in the case of emerging economies. It implies that the renewable energy sector needs more attention and investment to support the development process through private-public partnerships. While Rehman et al., (2021) witnessed that cleaner energy reduces economic growth in Pakistan. The findings reveal that a strong cleaner energy infrastructure is inevitable to attain economic and environmental sustainability. Liu et al., (2020) observed mixed results for the impact of renewable energy consumption on economic growth in the case of different-sized countries. Wei et al., (2022) found that renewable energy encourages sustainable development in the Asian economies and suggested reducing reliance on conservative energy sources to promote economic growth and a green environment. Thus, the following hypothesis holds for renewable energy-growth nexus.

Hypothesis 1: Renewable energy consumption elevates inclusive growth.

2.2 ICT Adoption and Inclusive Growth

Kumar (2014) and Niebel (2018) examined the effects of ICT access on economic growth by using a large sample of economies categorized into developing, emerging and developed economies. The outcomes exposed that developing and emerging economies are benefitting less from ICT in comparison to developed economies. Sawada et al., (2020) explained the importance of ICT as an enabler of information, technical and business inputs in Asia. Contrarily, Raheem et al., (2020) witnessed the negative impact of ICT on economic growth in the G-7 from 1990-2014. Habibi and Zabardast (2020) elaborated on the significant effects of ICT and education on economic growth in the case of the Middle East and OECD countries over the period 2000-2017. However, the intensity of the impact varies between the two samples through the use of different ICT measures. Khan et al., (2021) also found a positive association between ICT and economic growth in South Asian and African economies respectively. On the other side, Usman et al., (2020) considered time series data from South Asian countries and studied the impact of ICT on economic growth from 1990 to 2018. They observed that mobile phone subscription is positively and significantly associated with the economic growth of India only while negative and insignificant linkage is found between them in the case of other countries. Owolabi et al., (2021) employed multiple indicators for ICT and quantitative methods in the case of Sub-Saharan Africa. Their results confirmed that ICT imports and landlines increase while internet adoption decreases economic development.

Therefore, the mixed outcomes of the above studies induce this study to explore the following hypothesis:

Hypothesis 2: Internet technology accelerates inclusive growth.

2.3 Renewable Energy Consumption, ICT Diffusion and Inclusive Growth

The twenty-first century evolves with two serious concerns, energy shortage and environmental degradation for the global community. The volume and speed of the struggle to curb energy poverty and climatic changes are still insufficient. On the other side, cleaner and modern energy sources are a better substitute for conventional energy sources and are also capable of reducing climate change. Similarly, ICT in the form of Internet adoption has the potential to affect every sector of an economy directly as well as indirectly. Although the ICT industry itself is energy-intensive and has the potential to conserve energy through industrial optimization. Besides all, the existing literature very inadequately expresses the social outcomes of cleaner energy and the joint impact of Internet adoption and cleaner energy for inclusive growth. Stallo et al., (2010) focused that inclusive economic growth is achievable through the utilization of innovations and technologies in the form of renewable energy and Internet adoption. Similarly, Shruthi (2014) highlighted the reliable and transparent performance of Internet-driven smart grids to conserve modern energy and expenditure. Asongu et al., (2016) discovered a net positive impact of the interaction between information technology and renewable energy consumption to accomplish inclusive development in Sub-Saharan Africa. Ahmed et al., (2018) explained that ICT is the fastest-growing sector which is mandatory for modern infrastructure. It is an enabler of using cleaner and greener energy smartly to elevate energy efficiency and environmental quality. ICT raises the efficiency of renewable energy through the facilitation of storage and distribution of power. Contrarily, Chimbo (2020) found that ICT could not successfully complement energy consumption. Sinha et al., (2020) explored that the higher set-up cost of renewable energy hinders economic growth in Next-11 countries over the time 1990 to 2017. The outcomes suggested the reasonable use of innovations to enhance energy efficiency and awareness for reducing nonrenewable energy consumption. Hu et al., (2022) elaborated on the growth-cleaner energy-ICT nexus about cost and benefits inquiry, energy security, and greenhouse gas emissions. The outcomes witnessed a drastic increase in economic growth at domestic and foreign levels as a result of combining ICT and cleaner energy. Thus, the rising adoption of cleaner energy and ICT with limited research on the complementary role of ICT for renewable energy compels this study to do further work.

Hypothesis 3: The interaction of cleaner energy and Internet adoption significantly enhances inclusive growth.

East Asia has a remarkable adoption of renewable energy and the Internet in the last few decades. The economies in this region are investing a lot in renewable energy sources to make them affordable by all to reduce environmental degradation. Similarly, East Asian economies are focusing on the dissemination of ICTs not only to reduce the digital divide but also to flourish e-commerce and online businesses. In light of existing economic literature, it is deduced that the relationship between renewable energy-Internet-growth is complex. Moreover, the outcomes for individual and joint effects of the adoption of renewable energy and the Internet on inclusive growth are diversified in existing literature. Therefore, further research is needed to examine the impact of technological advancements in attaining inclusive growth to fill the gap in the literature.

3. Theoretical Framework

3.1 Growth Theories

Tracing back the theoretical underpinnings of the paradigm shift from economic to inclusive growth, Goulet (1971) established an ethical approach. He was of the view that real progress lies in maintaining equality, impartiality and social welfare along with an increase in the size of an economy. It shows that the essence of economic development is to protect the rights of people specifically the underprivileged segments. Therefore, researchers and economists believe that sustainable economic growth can be achieved by including marginalized people in the process and gains of economic growth. Then, Schumpeter (1975) emphasized that economic growth alone is unable to explain the process of development due to creative destruction. It means that technological innovations always replace the old techniques of production and leads to create unemployment and hinders development. Thus, economic growth is necessary to achieve economic prosperity, but it does not guarantee equal distribution of resources and participation of all individuals in the development process. Brundtland (1987) presented the sustainability approach which highlights the relationship between human lives and the environment in attaining sustainable growth. The welfare and empowerment theory also developed the ideology of the basic rights of every human (Sen, 2016). It infers that the provision of basic human rights such as food, shelter and job is the basic component of inclusive growth. All previous growth theories give rise to the concept of inclusive growth. Thus, inclusive growth is a long term and multifaceted phenomena which warrants the distribution of the economic benefits to all segments of the society equitably.

3.2 Technological Advancement Theories

Renewable energy and the Internet both are the latest technologies of the current era. Neoclassical growth theory deliberated the role of labor, capital and technology as the key drivers of economic growth (Solow 1956). Although labor and capital are scarce resources while growth effects of technology are infinite. The theory of circular economy describes the transition from fossil fuels to renewable energy. Renewable energy sources emit no or lesser carbon emissions thus they are not harmful to human health and the environment. Additionally, renewable energy projects are creating employment opportunities for all types of labor force right from scratch to completion. Similarly, digital technologies are affecting the output of an economy by providing widespread communication and transaction facilities. The theory of innovation explains that Internet adoption disseminates new ideas and expert opinions among the masses regarding novel techniques of production (Rogers et al., 2014). The use of internet saves time and resources of people and enables them to do online business across the globe. Thus the technical innovations are equipping the digital economy with energy efficient instruments which in turn are raising the demand for energy. Therefore, it is a dire need of the time to switch the energy sources from traditional to modern ones to avoid further environmental hazards. Both of these technologies support each other to promote inclusive growth. Renewable energy projects involve lots of data for which information and communication technology provide tools to analyze, compute and summarize. Previous studies do not adequately examine the individual and combined impact of renewable energy and the Internet on inclusive growth in East Asia. Moreover, the results of previous studies provide diverse findings due to some missing links between them. Therefore, the current research includes financial (capital) and human resources (labor), and external sector (trade openness) along with technology in the econometric model to obtain inclusive growth.

4. Methodology

4.1 The Data

The objectives of the current study are accomplished by an empirical analysis of the annual panel dataset for 25 years for East Asia⁴ (China, Hong Kong, Japan and Korea). The choice of countries and years is determined by the

⁴ East Asia comprises of seven economies according to World Bank. However, the data is not available for Mongolia, Macao and Taiwan.

availability of data. Specifically, the data for renewable energy use and Internet adoption is available after 1995 and till 2019⁵ for these economies.

4.1.1 Inclusive Growth (ING)

Inclusive growth (ING) is the dependent variable of this study. Past literature reveals different proxies for inclusive growth but there is no settlement of academicians on a single definition and measure of inclusive growth yet (Albagoury, 2021). GDP per capita and GDP per person employed are utilized as a proxy for inclusive growth by Sarabdeen et al., (2020) and Kouton (2021) respectively. Adeleye et al., (2021) and Batool et al., (2020) employed the human development index (HDI) as a proxy for inclusive growth. All these measures have certain limitations concerning the period, methods and selection of indicators. GDP per capita and GDP per person employed measure economic development only and overlook the equity dimension. Similarly, HDI focuses on the health, education and living standards of individuals of some specific country or area ignoring the disparities between different regions, gender and societal groups. To mend all these shortcomings, this study employs a wide-ranging and fresh index of Multidimensional Inclusiveness (MDI) for inclusive growth which accounts for the dimensions of development achievement, equity and ecology. This index is available in three versions and the basic version⁶ is used by this study to avoid multicollinearity with other variables. The other two versions are named as equity plus and achievement plus. The data is tracked from Dörffel and Schuhmann, (2022) and transformed into natural logarithm.

4.1.2 Renewable energy consumption (REN)

Renewable energy consumption (REN) is our independent variable which represents hi-tech modernization. There is not a variety of proxies used for cleaner energy in existing literature. Therefore, past research mostly utilized the percentage of modern and greener energy usage to probe the impact of renewable energy (Khalid et al., 2022). Jafari and Soltanzadeh (2019) relied on renewable energy capacity while Awolaja and Adenikinju (2019) engaged renewable energy production as a measure of modern energy consumption. The current study collected data for renewable energy consumption from the World Development Indicators (World Bank database, 2021).

⁵ This study is a part of author's PhD dissertation. The extensive empirical work is done by considering complete region Asia and its sub-regions.

⁶ This version provides data for a large number of economies but contains lesser variables than the other two versions. It includes sub-indices of income Gini, GDP per capita, savings, life expectancy and human capital.

4.1.3 Internet Adoption (INT)

The existing economic literature is enriched with many proxies used for different dimensions of ICT depending on the research design. The most commonly used proxies include access to the internet, number of fixed telephone lines and subscriptions to mobile phones. Few studies such as Devaraj and Kohli (2003) focused on the volume of online sales to examine their impact on economic growth. As the main purpose of this study is to explore the effects of Internet adoption on inclusive growth therefore this study utilizes Internet users (a percentage of the population) as a proxy for information and communication technology. The data is collected from the World Development Indicators (WDI database, 2021) of the World Bank.

4.1.4 Financial Development (FIND)

Financial development (FIND) is also the independent variable of the study. Extant literature mostly used a single indicator of financial development i.e., financial depth, access or efficiency of either financial institutions or markets. Domestic credit to the private sector, savings and broad money were used as financial development measures by Elfaki et al., (2021). Bahri et al., (2018) applied liquid liabilities, and private and domestic credit by banks as proxies for overall financial development. Whereas the International Monetary Fund indicated that a single indicator is inadequate to represent the overall financial development. Therefore, to correct this shortcoming, this study uses a broad-based financial development index (FDI) constructed by Sahay et al., (2015) for International Financial Statistics (IMF database). FDI consists of the size, inclusion and efficiency of all financial intermediaries altogether.

4.1.5 Control variables

The control variables of the study include participation rate of labor (LAB) and trade liberalization (TOP). The labor force between 15 to 64 years (percentage of the total population) and exports and imports (percentage of GDP) are used as proxies for LAB and TOP respectively. The data is traced from world development indicators of the World Bank.

4.2 The Model

The interplay between the usage of renewable energy and the Internet for inclusive growth can be symmetric or asymmetric. This is because of the complex nature of the relationship between these variables. Further, this asymmetric behavior may be due to the difference in the access and adoption of the Internet and renewable energy in different regions or countries. Therefore, following

endogenous growth theory⁷, an augmented Schumpeterian growth model is formed as under:

$$ING_{i,t} = \alpha_{i,t} + \beta_1 REN_{i,t} + \beta_2 INT_{i,t} + \beta_3 (REN \times INT)_{i,t} + \beta_4 FIND_{i,t} + \beta_5 LAB_{i,t} + \beta_6 TOP_{i,t} + \varepsilon_{i,t} \quad (1)$$

Here, *ING*, *REN* and *INT* indicate inclusive growth, renewable energy consumption and Internet technology respectively. *FIND* is used for financial development. *LAB* and *TOP* are used for the labor force and trade openness respectively. β_s show the long-run coefficients while *i* and *t* denote countries and years respectively. While α and ε depict constant and random error terms respectively.

4.3 Estimation approaches

4.3.1 Panel Autoregressive Distributed Lag (ARDL)

To investigate the association between cleaner energy, Internet adoption and inclusive growth in East Asia, a panel Autoregressive distributed lag (ARDL) approach will be applied. The panel ARDL model was first presented by Pesaran and Shin (1998). The panel ARDL model provides long and short-run estimations along with an error correction model and addresses the issues of endogeneity. In addition, panel ARDL caters to variables either stationary at a level, first differenced or mixed. The short-run dynamics are included in Equation 1 as follows:

$$\begin{aligned} \Delta ING_{it} = & \alpha_0 + \sum_{m=1}^n \phi_{1m} \Delta ING_{t-m} + \sum_{m=0}^n \phi_{2m} \Delta REN_{t-m} + \\ & \sum_{m=0}^n \phi_{3m} \Delta INT_{t-m} + \sum_{m=0}^n \phi_{4m} \Delta (REN \times INT)_{t-m} + \sum_{m=0}^n \phi_{5m} \Delta FIND_{t-m} + \\ & \sum_{m=0}^n \phi_{6m} \Delta LAB_{t-m} + \sum_{m=0}^n \phi_{7m} \Delta TOP_{t-m} + \beta_1 REN_{i,t} + \beta_2 INT_{i,t} + \\ & \beta_3 (REN \times INT)_{i,t} + \beta_4 FIND_{i,t} + \beta_5 LAB_{i,t} + \beta_6 TOP_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2)$$

In Equation 2, Δ denotes the first difference variables while ϕ_s shows the short-run dynamics and ε depicts the error term. Now, after including an error correction term in Equation 2, the complete ARDL model is presented as follows:

$$\begin{aligned} \Delta ING_{t-j} = & \beta_0 + \sum_{j=1}^k \omega_{1j} \Delta ING_{t-j} + \sum_{j=1}^k \gamma_{2j} \Delta REN_{t-j} + \sum_{j=1}^k \delta_{3j} \Delta INT_{t-j} + \\ & \sum_{j=1}^k \psi_{4j} \Delta (REN \times INT)_{t-j} + \sum_{j=1}^k \eta_{5j} \Delta FIND_{t-j} + \sum_{j=1}^k \tau_{6j} \Delta LAB_{t-j} + \\ & \sum_{j=1}^k \tau_{7j} \Delta TOP_{t-j} + \beta_1 REN_{i,t} + \beta_2 INT_{i,t} + \beta_3 (REC \times INT)_{i,t} + \beta_4 FIND_{i,t} + \\ & \beta_5 LAB_{i,t} + \beta_6 TOP_{i,t} + \theta ECT_{i,t-1} + \varepsilon_{i,t} \end{aligned} \quad (3)$$

⁷ This theory focuses that economic growth is the outcome of internal factors such as investment in human capital, information and technology.

Θ represents the coefficient of the lagged error correction term.

4.3.2 Panel Nonlinear Autoregressive Distributed Lag (NARDL)

The panel NARDL approach was suggested by Shin et al., (2014) to explore a nonlinear relationship between variables of interest. The existing literature proves that the association between economic variables is mostly asymmetric, and application of linear approaches may lead to incorrect inferences. In addition, this technique provides deeper insights than panel linear ARDL by providing the direction and intensity of the increase and decrease in explanatory variables on the explained variable. NARDL is more flexible than other conventional econometric procedures that assume a linear association only. It is important because many economic relationships are asymmetric and the application of linear methods for them may lead to spurious outcomes. Further, the panel NARDL accounts for structural breaks in the datasets. Thus this method provides complete dynamics before and after the structural break. Most importantly, the panel NARDL findings are easy to implement and interpret. Therefore, the following nonlinear model is demonstrated to examine the nonlinear impact of cleaner energy and internet adoption on inclusive growth:

$$ING_{i,t} = \alpha_{i,t} + \beta_1 REN_{i,t} + \beta_2 INT_{i,t} + \beta_3 (REN \times INT)^+_{i,t} + \beta_4 (REN \times INT)^-_{i,t} + \beta_5 FIND_{i,t} + \beta_6 LAB_{i,t} + \beta_7 TOP_{i,t} + \varepsilon_{i,t} \quad (4)$$

In Equation 4, all the descriptions are the same as before except for the interaction term of renewable energy consumption and the Internet (RENxINT). The increase and decrease in the interaction term is represented as:

$$(REN \times INT)_t = (REN \times INT)_0 + (REN \times INT)^+ + (REN \times INT)^- \quad (5)$$

$$(REN \times INT)_t^+ = \sum_{i=1}^t \Delta REN \times INT_i^+ = \sum_{i=1}^t \max(\Delta REN \times INT_i, 0) \quad (6)$$

$$(REN \times INT)_t^- = \sum_{i=1}^t \Delta REN \times INT_i^- = \sum_{i=1}^t \min(\Delta REN \times INT_i, 0) \quad (7)$$

Here, $(REN \times INT)_t^+$ and $(REN \times INT)_t^-$ represent the increase and decrease in renewable energy consumption and Internet adoption respectively. Δ displays the first difference operator, $\Delta (REN \times INT)_i = (REN \times INT)_i - (REN \times INT)_{i-1}$. Thus Equation 4 is rearranged after adding the representation of short- and long-term dynamics and error correction.

$$\begin{aligned} \Delta ING_{t-j} = & \beta_0 + \sum_{j=1}^k \omega_{1j} \Delta ING_{t-j} + \sum_{j=1}^k \vartheta_{2j} \Delta REN + \sum_{j=1}^k \delta_{3j} \Delta INT_{t-j} + \\ & \sum_{j=1}^k (\gamma_{4j}^+ \Delta REN \times INT_{t-j}^+ + \gamma_{4j}^- \Delta REN \times INT_{t-j}^-) + \sum_{j=1}^k \psi_{5j} \Delta FIND_{t-j} + \\ & \sum_{j=1}^k \eta_{6j} \Delta LAB_{t-j} + \sum_{j=1}^k \tau_{7j} \Delta TOP_{t-j} + \beta_1 REN_{i,t} + \beta_2 INT_{i,t} + \\ & \beta_3 REN \times INT_{i,t} + \beta_4 FIND_{i,t} + \beta_5 LAB_{i,t} + \beta_6 TOP_{i,t} + \sigma ECT_{i,t-1} + \varepsilon_{i,t} \end{aligned} \quad (8)$$

k and σ denote lag size and lagged ECT respectively in Equation 8

5. Results and Discussions

Table 1. Description of the variables

	ING	REN	INT	FIND	LAB	TOP
Mean	3.807	1.078	3.285	-0.389	4.279	4.284
Median	3.757	1.295	4.032	-0.295	4.282	4.066
Maximum	4.121	3.418	4.564	-0.111	4.423	6.092
Minimum	3.307	-0.644	-4.336	-1.025	4.154	2.903
Std. Dev.	0.287	1.299	1.815	0.235	0.072	0.972

Source: Own calculations

Table 2. Correlation Matrix

ING	1					
REN	-0.467	1				
INT	0.454	-0.425	1			
FIND	0.392	-0.386	0.409	1		
LAB	-0.570	0.476	-0.423	0.606	1	
TOP	-0.200	0.223	-0.665	0.251	-0.393	1

Source: Own calculations.

Table 3. Panel Unit Root Tests

Variables	Test	Intercept		Intercept and trend		
		I(0)	I(1)	I(0)	I(1)	
ING	IPS	-0.531	-2.046**	-0.321	-1.979**	I(1)
	ADP	9.799	16.304**	8.515	15.576**	
	PP	3.685	16.783**	2.177	29.225*	
REN	IPS	1.751	-3.041*	0.846	-2.748*	I(1)
	ADP	4.856	24.530*	6.059	22.420*	
	PP	4.062	46.042*	3.749	50.821*	
INT	IPS	-23.365*	-3.298*	-27.424*	-5.912*	I(0)
	ADP	240.648*	26.362*	332.244*	45.342*	
	PP	89.902*	16.670**	6.823	40.604*	
FIND	IPS	-1.912**	-7.465*	-2.111**	-6.856*	I(0)
	ADP	20.530*	62.164*	21.179*	54.874*	
	PP	25.233*	58.211*	15.511**	51.736*	
LAB	IPS	2.694	-3.503*	1.861	-3.563*	I(1)
	ADP	6.156	27.350*	5.167	25.994*	
	PP	1.080	24.585*	0.885	24.471*	
TOP	IPS	0.157	-3.332*	1.628	-2.554*	I(1)
	ADP	5.216	25.936*	3.142	19.759**	
	PP	4.655	46.670*	3.517	37.733*	

Note: * and ** denote 1 and 5 per cent significance level. Null hypothesis: Data series contain a unit root.

The application of any econometric method demands fulfilling some prerequisites; therefore, the description of variables is presented in the upper segment of Table 1. It contains the mean, median, maximum, minimum values and standard deviation of the dependent and independent variables. The lower segment of Table 1 describes the pairwise correlation between the variables of the study. The correlation between inclusive growth and renewable energy is negative while it is positive between Internet adoption, financial development and inclusive growth. Likewise, it is seen that all the variables are correlated with inclusive

growth differently. After reviewing the descriptive statistics and correlation matrix, the next step is to examine the stationarity status of the variables. This is done by applying IPS, ADF and PP panel unit root tests and the results are displayed in Table 2. It is ascertained from the findings of multiple tests at the level and the first difference that variables have mixed order of integration. Thus, the mixed order of variables confirms the application of panel ARDL and NARDL.

Next, the panel co-integration tests are employed to ensure the presence of cointegration among the selected variables of the whole panel. Table 3 reports that the highly significant probability values in four out of seven tests of Pedroni as well as the Kao panel co-integration test permit us to reject the null hypothesis concluding that all the analyzed variables have a long-run relationship.

Table 3: Panel Co-integration Tests

Common AR coefficients		Individual AR coefficients	
Pedroni test	Statistics		Statistics
	6.06*		1.96
Panel v-Statistic	(0.00)	Group rho-Statistic	(0.97)
	1.25		1.16
Panel rho-Statistic	(0.89)	Group PP-Statistic	(0.87)
	0.80*		-2.75*
Panel PP-Statistic	(0.00)	Group ADF-Statistic	(0.00)
	-2.38*	Kao co-integration test	-1.67**
Panel ADF-Statistic	(0.00)		(0.04)

Note: * and ** denote a 1 and 5 per cent level of significance. Probabilities are shown in (). Both tests have same null hypothesis, “no co-integration”.

After fulfilling the prerequisites, the linear and nonlinear ARDL approaches are applied and the results are shown in Table 4. The results of linear ARDL disclose that the usage of REN enhances inclusive growth significantly in the long run. It indicates that a one per cent increase in cleaner energy consumption raises inclusive growth by 0.106 per cent on average assuming the other elements are fixed. It is similar to (Sadraoui et al., 2019; Majeed et al., 2021) and confirms hypothesis 1 of the current study. It implies that renewable energy ventures are increasing investment opportunities in East Asian economies leading to poverty eradication by job creation. On the flip side, the NARDL findings report the deteriorating effect of REN on inclusive growth during the same time. It shows that inclusive growth is reduced by 0.040 per cent due to a one per cent increase in renewable energy usage. It opposes the results of (Azam et al., 2021) while confirms the findings of (Shukla et al., 2017) and rejects hypothesis 1. It infers that renewable energy itself is not harmful, rather there are many factors including implementation and infrastructural problems responsible for its adverse impact. East Asian countries are still heavily dependent on fossil fuels. A rapid shift from

conventional to modern energy sources may lead to certain economic and industrial disturbances such as unemployment, poverty and inequality. This result concludes that the positive impact (ARDL) of REN is larger than the negative effect (NARDL).

Internet adoption has proved significant and favorable for inclusive growth according to the results of the ARDL approach accepting hypothesis 2. While it is insignificant according to NARDL rejecting hypothesis 2. Specifically, inclusive growth upturns by 0.056 per cent as a result of a one per cent increase in Internet access assuming other things are unchanged. It is consistent with (Habibi and Zabadast, 2020; Majeed et al., 2021; Adeleye et al., 2022; Khalid et al., 2023). It demonstrates that Internet adoption is playing a vital role in supporting inclusive growth by providing easy access to information, job opportunities, and improving health and education facilities. Moreover, the adoption of the Internet is opening new avenues for the marginalized population by providing access to affordable loans, mobile banking and e-commerce. Thus ICT-led financial inclusion and technological advancements stimulate inclusive growth. The findings of both approaches contradict each other in the case of REN and INT.

The long-run findings of linear ARDL disclose negative and significant joint effects of renewable energy and Internet adoption on inclusive growth thus denying hypothesis 3. It is shown that a one per cent increase in RENxINT decreases inclusive growth by 0.015 per cent. This finding concludes that the combination of cleaner energy and Internet adoption fails to favor inclusive growth. Contrarily, the results of the NARDL approach support the complementary role of Internet adoption for renewable energy consumption to enhance inclusive growth. More specifically, a one per cent increase in RENxINT escalates inclusive growth significantly by 0.012 per cent. Whereas, a one per cent decrease in RENxINT is responsible for a 0.020 decrease in inclusive growth on average. Although the effect of a decrease in RENxINT is larger than the increase in RENxINT for inclusive growth. However, this finding highlights the successful joint role of RENxINT for inclusive growth and confirms hypothesis 3. The difference in magnitudes and signs of coefficients for increase and decrease in interaction term confirms the existence of nonlinearity between RENxINT and inclusive growth. In other words, the increase and decrease in the combination of REN and INT has the potential to affect ING differently in East Asia depending on country-specific policies.

The findings of ARDL (NARDL) reveal that financial development decreases (increases) inclusive growth significantly in the long run. The positive association is similar to (Odugbesan et al., 2021) while the negative relationship

confirms the work of (Manigandan et al., 2023). It implies that an efficient financial sector is inevitable for managing savings and funds to invest them in the most productive businesses by ensuring the participation of underserved segments of society. Both techniques report the positive impact of the LAB and TOP on inclusive growth during the same period.

The short-term estimates of the NARDL approach reveal that previous period inclusive growth and renewable energy consumption support inclusive growth significantly while financial development declines inclusive growth. The error correction terms of both models are statistically significant and carry negative signs indicating the convergence towards long-run equilibrium.

Table 4. Linear and Nonlinear ARDL estimates

Long-run equations: Dependent Variable=ING						
Variables	ARDL Model			NARDL Model		
	Coefficient	Std. error	t. stat	Coefficient	Std. error	t. stat
REN	0.106*	0.020	5.129	-0.040*	0.010	-3.822
INT	0.056*	0.009	6.005	-0.008	0.009	-0.890
RENxINT	-0.015*	0.003	-4.044	-	-	-
(RENxINT)_Pos	-	-	-	0.012*	0.003	3.806
(RENxINT)_Neg	-	-	-	0.020***	0.011	1.838
FIND	-0.225*	0.045	-4.969	0.208*	0.059	3.482
LAB	0.166**	0.076	2.180	0.506*	0.179	2.815
TOP	0.081*	0.006	12.176	0.070*	0.016	4.176
Short run equations						
ECT(-1)	-0.655*	0.161	-4.056	-0.407*	0.096	-4.230
ΔING	0.256	0.158	1.617	0.206*	0.087	2.347
ΔREN	0.080	0.218	0.370	0.016**	0.006	2.516
ΔINT	-0.049	0.115	-0.46	-0.041	0.034	-1.204
Δ(RENxINT)	-0.009	0.060	-0.160	-	-	-
Δ(RENxINT)_Pos	-	-	-	0.007	0.011	0.641
Δ(RENxINT)_Neg	-	-	-	0.021	0.029	0.718
ΔFIND	0.121	0.073	1.644	-0.029***	0.011	-2.511
ΔLAB	2.602	2.021	1.287	0.805	0.915	0.879
ΔTOP	-0.015	0.021	-0.737	0.007	0.012	0.596
Constant	1.624*	0.507	3.204	0.654*	0.209	3.120

Note: t-stats are given in (). *, ** and *** show significance levels at 1, 5 and 10 per cent respectively.

Table 5. Post-estimation diagnostics

Tests	Chi-square statistics	
	ARDL model	NARDL model
Normality	2.217 (0.32)	5.184 (0.07)
Serial correlation	3.199 (0.20)	2.236 (0.13)
Functional form	1.358 (0.19)	1.147 (0.28)
Heteroscedasticity	10.41 (0.11)	15.41 (0.22)

Note: Probability values are shown in (). Source: Own calculations. Null hypothesis (all tests): No issue in the model.

Lastly, the results of the post-estimation diagnostics of ARDL and NARDL models are presented in Table 5. The findings of statistically insignificant probabilities for all tests accept the null hypothesis concluding that both models do not have issues of non-normality, serial correlation, incorrect functional form and heteroscedasticity.

6. Conclusion

The current research aims to connect renewable energy consumption (SDG, 7), Internet adoption (SDG, 9) and financial development as potential drivers for the accomplishment of inclusive growth (SDG, 8) in East Asia from 1995 to 2019. The primary purpose of the current study is to perform a comparative analysis by using both the latest and traditional approaches. The study adds to the extant economic literature by using a balanced panel dataset of East Asian economies to examine the attainment of inclusive growth rather than economic growth, utilizing linear and nonlinear frameworks. In addition, the current study uses a comprehensive and newest measure of the Multidimensional Inclusiveness Index for inclusive growth. Further, this study selects Internet adoption, which is an important form of ICT. Unlike previous studies, this paper contributes to the literature by highlighting the social and economic benefits of cleaner energy rather than just ecological effects. This paper discovers the overall impact of financial sector expansion on inclusive growth by employing the broader IMF index despite using either an indicator measuring a single dimension for financial institutions or markets. Finally, this study is one of the very few studies, which analyzes the direct as well as indirect impact of Internet technology on cleaner energy to realize inclusive growth in East Asia.

The findings of the study through ARDL and NARDL approaches reveal that renewable energy, Internet adoption and financial development are exigent determinants of inclusive growth. More specifically, the ARDL findings prove that the adoption of renewable energy and the Internet increases while financial development decreases inclusive growth significantly in the long run. The outcomes of the NARDL approach reveal that usage of renewable energy and Internet adoption reduces while financial development increases inclusive growth during the same period. In addition, the findings of ARDL prove that the mediating role of Internet adoption remains unsuccessful in supporting renewable energy to enhance inclusive growth. On the contrary, the results of NARDL prove that the combination of renewable energy and Internet adoption is beneficial to achieve inclusive growth. The increase (decrease) in interaction term increases (decreases) inclusive growth significantly in the long run. The NARDL confirms the existence

of significant asymmetries between the interaction term (RENxINT) and inclusive growth by providing deeper insights than ARDL.

6.1 Policy Implications

In line with the above findings, it is suggested that:

- East Asian economies should invest in technical education and awareness programs to equip the local communities with the skills required for employment in the renewable energy sector.
- The governments must align the cleaner energy projects with the local needs and culture by including the community representatives in planning, decision and policy-making. All these steps will ensure the contribution of economic benefits for the domestic economy and inclusive growth.
- Provision of subsidies and microfinancing to warrant that renewable energy sources are within the reach of low-income people is mandatory.
- Policies to increase investment to upgrade digital and broadband infrastructure are also suggested to provide uninterrupted and high-speed internet in rural areas.
- Special attention should be given towards enhancing digital literacy and the provision of the Internet at affordable rates to promote inclusiveness.
- To establish clear regulatory frameworks providing a conducive environment for consumer protection, data security and a suitable environment is a must.
- International and regional collaborations should be made to share best practices, expertise and experiences in the fields of cleaner energy and ICT so that their individual and joint role can be translated into inclusive growth.

6.2 Future Recommendations

This research explores the dynamic effects of renewable energy, Internet adoption and financial development on inclusive growth from 1995 to 2019, using linear and nonlinear ARDL in the case of East Asia. The new research can be conducted by using the latest methods and materials using more data either for a single country or other regions of the world.

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