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Impact of Knowledge-Based Economy on Climate Change: A Comparative Study of Asian Developing and G-7 Countries

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ABSTRACT

Climate change can be observed in all aspects of nature's behaviour. The terrible implications of climate change for the planet and its inhabitants necessitate immediate intervention. The UN SDGs aim to address global, regional, and national development needs. This study examines the link between the knowledge-based economy and SDG13-Climate Action using annual balanced panel data from 2000 to 2023 for Asian developing and G7 countries. A series of pre-estimation tests, including cross-sectional dependence, panel unit root tests and panel cointegration tests. The second-generation CS-ARDL model is employed to analyse short-run and long-run dynamics. The panel causality test evaluates causal links between the variables. The results indicate a substantial adverse effect of the knowledge-based economy on climate change in both advanced and developing countries. Renewable energy consumption and foreign direct investment mitigate climate change, whereas urbanization exacerbates it. The p-value of KE in developing nations is 0.05, indicating a 5% upsurge in KE leads to a 0.20% reduction in climate change in the long run. Advanced G7 nations parameter values show a 1% increase in KE leads to a 3.79% reduction in climate change in the long run. The results demonstrate that G7 countries, with their advanced knowledge infrastructures, high levels of technological innovation, and robust institutional frameworks, are better positioned to integrate KE principles into climate action policies. While Asian developing countries, face structural constraints that hinder their ability to leverage the knowledge economy for climate action effectively. The research provides stakeholders, investors, and policy makers with valuable insights.

Keywords Knowledge Based Economy, Climate Change, Cs-Ardl, Selected Sustainable Development Goals

Introduction

Climate change represents one of the most pressing sustainability challenges confronting contemporary development pathways. Rising global temperatures, increasing frequency of extreme weather events, and accelerating ecological degradation threaten economic stability, social welfare, and environmental integrity across countries at different stages of development. These challenges are particularly salient in the context of the United Nations Sustainable Development Goals (SDGs), which emphasize the need to



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harmonize economic progress with environmental protection and social inclusion. Among these goals, SDG 13 (Climate Action) occupies a central position, as climate risks increasingly undermine progress toward poverty reduction, food security, health outcomes, and long-term development resilience. By reducing negative effects and limiting the temperature increase to less than 1.5° by the end of this century, SDG-13 (Climate Action) create strategies for low-carbon development. Many economies have been experiencing the effects of climate change for a long time. It seriously jeopardises human health, economic stability, and natural ecosystem (createt al., 2025a). Climate change has the potential to worsen already-existing social and economic disparities. Additionally, it hinders efforts to reduce poverty, and jeopardise access to clean water, food security, and health consequences. Vulnerable groups in small states, developing nations, and marginalised communities, are disproportionately influenced by climate change (Elavarasan et al., 2022; Rasheed et al., 2025b). GHG levels are 50% greater now than they were in 1990. Climate change has long been a result of global warming. Because of the increasing negative effects on the economy, ecology, and society, it has long been a global issue. Climate threats disproportionately affect Asia (Leung et al., 2023).

The Sustainable Development Goals provide a global framework for advancing environmental sustainability, social inclusion, and economic development. They were formally adopted by world leaders at the United Nations in New York on 25 September 2015. To attain social, economic, and environmental sustainability by 2030, they unveiled a demanding agenda with 17 objectives and 169 targets (UN, 2015). This agenda seeks to address persistent inequalities that limit large segments of the population from fully realizing their fundamental rights. (Prieto-Egido et al., 2023). The Sustainable Development Goals (SDGs) are an extension of the Millennium Development Goals (MDGs) with 67 goals. MDGs target time span from 2000 to 2015. Increasing national averages was the main objective of the MDGs framework. To put the fundamental idea of "leaving no one behind" into operation, the SDGs must address national development disparities (Mishra et al., 2024). Although the SDGs are essentially an updated version of the MDGs. The paradigm they reflect is not wholly new. By emphasising the Triple E; Economy, Equality, and Ecology, the sustainable development goals aim is to balance the process of progress. Politicians and bureaucrats would have a broader perspective beyond their own national interests by 2030, according to the SDGs. A key blueprint for a more sustainable future, the SDGs promote innovations, healthy lifestyles, energy-efficient economies, human well-being, and ecologically responsible production and consumption (Jednak & Krgulj, 2015; Ivanova & Boncheva, 2021; Chein, 2022). One of the biggest challenges that humanity has faced is sustainable development. In order to address economic, social, and environmental issues all at once, nations are actively looking at ways to support the transition of national sustainable development (Fernandes et al., 2022; Lu et al., 2020). The Sustainable Development Goals, which stress the value of interested parties and cross-sectoral and multinational collaboration for sustainable development, were proposed by the UN in 2015.

The pursuit of the SDGs is a multifaceted and intricate undertaking. It necessitates concerted international, national, and local initiatives. It impede development on several fronts. Sustainability initiatives are threatened by ecological issues such as resource depletion and global warming. Attempts to implement and enforce the SDGs may be thwarted by unrest in politics, violence, and corruption(Singh et al., 2023). This shift from the traditional production system to a more service-orientated economy known as the "knowledge-based economy". Knowledge-based economies facilitate collaborative



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research, development, and international partnerships, which are essential for achieving the targets of SDG13 (Ibrahim et al., 2024). Over the past 20 years, the global economy has undergone significant changes due to globalisation, technological progress, disparity in the scope of work, and changes in management systems. Economic and institutional frameworks, education and skills, an efficient innovation system, and information communication and technology are the four main pillars that make up a knowledge-based economy. These all come together under a single overarching framework (Kalim et al., 2024; World Bank, 2015). Particularly when it comes to environmental degradation (Ganda, 2019), these pillars are crucial for taking the policy aspect into account (Martínez et al., 2021). These metrics are related to consumption in order to make it environmental friendly and sustainable with economic growth. The KE's mechanism route for lowering carbon emissions is simple. First, more education raises human capital and awareness, which in turn boosts production and consumption efficiency, and eventually, lowers carbon emissions (Zafar et al., 2020; Doğan et al., 2020). Second, institutions have a comparable function in preventing environmental degradation. Effective institutional quality has the ability to counteract both production-side and consumption-side polluting influences. Thirdly, technology is always significant. Every economy needs effective and eco-friendly technology to assist in preventing environmental degradation (Li et al., 2023). Fourth, innovations contribute to the decrease of carbon emission. As advancements proliferate, current technology is improved to become more eco-efficient. Innovations contribute to lowering carbon emissions in this way (Arshed et al., 2022).

Knowledge economy promotes informed action, sustainable innovation, and international collaboration (Zhang et al., 2023). In essence, it is an economic system in which the creation, sharing, and use of information are the primary drivers of development, wealth creation, and job creation (Banmairuoy et al., 2022). Particularly, countries need knowledge-based economies to take advantage of global economic possibilities as well as to improve their local economic capacities. Utilising knowledge is now recognised as a key driver of growth, productivity, and competitiveness in the global economy. Examples of this include research and development, entrepreneurial activities and innovations, and the improvement of education and skills among individuals (Petrushenko et al., 2022; Phale et al., 2021). Integrating information into manufacturing processes is mostly done by humans. Technology facilitates these processes by accelerating them and disseminating knowledge. The main factor driving productivity development is intellectual capital. Understanding the complex interplay between humans and machines, innovation and accuracy, and creativity and quality is essential for effective operations. The influence of knowledge generated inside industrial processes with the aid of several elements like technology, digital advancement, managerial abilities can transcend the importance of holding original information connected to people (Serban, 2022; Tew et al., 2017).

Comparing Asian developing countries and G-7 countries highlights the differences in economic structures, levels of development, and resource availability. This comparison provides insights into how various economic and developmental stages mitigates climate change to achieve SDG-13 (Climate Action). G-7 countries, being highly industrialised, have historically contributed more to greenhouse gas emissions. In contrast, Asian developing countries are currently experiencing rapid industrialisation and urbanisation, which contributes to increasing emissions. Understanding these dynamics can help in formulating tailored climate policies that address both historical responsibilities and current emission trends. Asian developing countries often face greater vulnerability to



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climate change impacts due to factors. These are geographical location, economic dependence on climate-sensitive sectors (e.g., agriculture), and limited adaptive capacity. G-7 countries generally have more resources and infrastructure to adapt to climate change. This comparison can shed light on the varying needs and capacities for climate adaptation and resilience. G-7 countries typically have more established policies and greater financial and technological resources to address climate change. Analysing their strategies can provide valuable lessons for Asian developing countries. Conversely, innovative approaches from Asian developing countries, driven by necessity and resource constraints, can also offer useful insights for G-7 countries.

This study contributes to the environment–development–sustainability literature by examining the knowledge-based economy as a systemic determinant of climate action rather than focusing on isolated components such as education or innovation. It provides novel comparative evidence for Asian developing and G7 countries, highlighting how differences in development stages, institutional capacity, and technological advancement shape the effectiveness of knowledge-driven strategies in mitigating climate change. By strengthening the empirical understanding of the environment–development nexus, the study demonstrates that knowledge-based economic transformation can support climate mitigation while remaining compatible with development objectives. Methodologically, it advances sustainability research by applying second-generation panel techniques that account for cross-sectional dependence and heterogeneity, thereby improving the robustness of long-run and short-run estimates. Finally, the findings offer policy-relevant insights for aligning investments in knowledge infrastructure, innovation systems, and institutional quality with SDG 13–Climate Action across diverse economic contexts.

This study then proceeds like this: the second portion includes some theoretical and scientific analysis that analyses the function of the individual pillars of knowledge-based economy in achieving 13th sustainable development objective the climate change. The third portion discusses the analytical model, data, and methods for approximating the empirical model; the fourth section discusses the empirical results. Additionally, the fifth section, which also elaborates on the study's limitations, provides the results and policy recommendations.

Literature Review

This study's literature review is twofold. First, it examines the theoretical literature on how climate change and the study's independent variables are connected. Second, reviews of empirical research that is either directly or indirectly relevant to this topic are included in this part. Reviews of empirical research are separated into two categories: reviews of previous research on climate change in South Asia and reviews of previous research on climate change in other locations.

Theoretical Framework

Every element of human life is impacted by climate change in intricate ways. The implications of Climate Change on health can be attributable to the immediate impacts of exposure to extreme weather instances, such as heat stress, floods, drought, and severe weather, with subsequent increases in pulmonary and cardiac morbidity and mortality (Yang et al., 2018). Indirect consequences include food shortages, human displacement, disease vector spread, mental health issues linked to natural disasters, and poor air quality. Furthermore, these effects can be amplified by economic disruptions and diminished governance capacity. Accordingly, it is estimated that between 2030 and 2050, Climate Change will result in an additional 250,000 fatalities per year (WHO 2018). According to Alborn-Morant et al. (2018), knowledge-intensive organisations



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continuously assess their environmental impact in addition to promoting the production of knowledge and the invention of environmentally friendly goods. The Brookings Institution claims that by utilising computerised devices, leading-edge high-technology concepts, and talents to revolutionise conventional work techniques, digitalisation affects the socioeconomic and even environmental dynamics of communities. The innovative use of computer-controlled resources in place of traditional ways for profitable, cost-effective, and environmentally friendly operations is at the forefront of digitalisation (Balogun, 2020). Another way to observe knowledge is through the production-related economic complexity channel. When it comes to cutting carbon emissions, the KE's mechanism channel is simple (Zafar et al., 2020). First, more education raises human capital and understanding, which boosts production and consumption performance and, eventually, lowers greenhouse gas emissions (Cordero et al., 2020). Second, institutions have a similar role in preventing environmental degradation (Sabir et al., 2020). Effective institutional quality has the ability to counteract both production-side and consumption-side polluting influences. Thirdly, technology is always important; as it helps prevent environmental degradation, effective and eco-friendly technology is always required in any economy. Thirdly, technology is always important. Every economy needs effective and environmentally conscious innovation because it assists in managing environmental degradation. The fourth point is that technologies help reduce emissions of carbon (Arshed et al., 2021). As advancements proliferate, current technology is improved to become more eco-efficient. Innovations contribute to lowering carbon emissions in this fashion.

Literature makes it clear that the world would eventually move closer to sustainability if energy sources based on fossil fuels were substituted with renewable ones, like renewable energy, direct solar energy, geothermal energy, hydropower, wind, and marine power (tide and wave). With the opportunities created in recent decades to replace petroleum-derived materials from fossil fuel-based energy sources with alternatives in renewable energy sources, administrations, collaborative agencies, stakeholders, and individuals around the world look ahead to achieve a sustainable future. The focus of many countries' most recent national policies, strategies, and developmental plans is sustainable development. The SDGs prioritise and require more from the scientific community than the Millennium Development Goals did. Climate change, renewable energy, food, health, and water supply all require coordinated global monitoring and modelling of a number of societal, economic, and environmental factors (Abbass et al., 2022). Therefore, based on these considerations, it may be hypothesised that achieving the underlying targets for SDG8, SDG10, and SDG7 is also crucial to achieve SDG13. Küfeoğlu (2022) predicted knowledge based economy significant effects on the economy and improve people's quality of life. Additionally, because it promotes the creation of a comfortable workplace, the maintenance of a healthy workforce, and the protection of natural means for the present and the future. Preserving the environment is crucial for sustainable development (Liu et al., 2022). Employing sources of clean energy that don't release greenhouse emissions, like biomass, biofuel, solar, wind, hydro, and tidal power, can help attain this goal (Ngo, 2024)

Empirical Framework

Regarding the SDG13, mitigation of CO₂ emissions, economic activity is thought to have both a positive and negative impact on CO₂ emissions (Adebayo et al., 2021). Comparably, the growth of the financial industry has also been connected to a range of environmental effects, including both increased and decreased CO₂ emissions (Dingru et al., 2021). Additionally, many researchers have correctly recognised that the usage of



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energy resources particularly dirty ones is a major cause of increased CO₂ emissions in the atmosphere (Khan et al., 2021). In particular, these studies have argued that burning fossil fuels releases CO₂ and other greenhouse gases into the atmosphere. On the other hand, using renewable energy is acknowledged as a way to reduce these emissions (Koonthar et al., 2021). The number of fatalities from natural disasters can change yearly. Certain years may go by with very few fatalities before an enormous catastrophe event takes many lives. Over the previous ten years, natural disasters killed an average of 60,000 people worldwide each year (Wiranata and Simbolon, 2021). According to Chowdhury et al. (2021), waste management comes next in terms of CO₂ emissions. According to the literature, energy efficiency and REs are the primary instruments for reducing climate change and accomplishing the objectives established at the several summits. The complexity of the strategy is in the necessity of transforming existing energy systems to renewables, which will guarantee energy security and enhance health and quality of life (Abbasi et al., 2020). Though it is linked to climate policies, the deployment of renewables is insufficient to stop even an increase in emissions. Given that globalisation is speeding up economic development worldwide. It requires a move towards renewable energy sources (REs) that lower greenhouse gas emissions. Its initiatives are targeted towards at mitigating the causes and effects of climate change (Puertas & Marti 2021).

Furthermore, public concerns are exacerbated by a lack of ecological information and understanding, antiquated consumer conduct, a lack of incentives, a lack of legislation, and the government's dearth of enthusiasm for combating climate change. A significant change in rainfall patterns and a 2–3% increase in mercury by 2050 could have detrimental effects (Huang et al., 2022). Digitalisation of climate data preserves past observations, aiding in understanding and forecasting climate variability and extreme events for preparedness. Digital technology offers a method for collecting substantial, high-quality data that can bolster examinations of exposure and susceptibility. Digitalisation promotes a more decentralised approach to decision-making. Digitalisation is one of the forces behind the world economy, and data generated by networked devices promotes prudent innovation and resource efficiency (Quandt et al., 2023). Since CO₂ emissions are rapidly increasing and endangering the environment in which humans live, special attention should be given to them. China, the largest CO₂ emitter, has emphasized that achieving CO₂ neutrality necessitates a substantial and comprehensive structural transformation of its economy and society (Zang et al., 2023).

The earlier assessments of previous research describe the various factors that contribute to climate change, including energy consumption, GDP, globalisation, foreign direct investment, industrialisation, and urbanisation.

However, none of these studies examined the part that the knowledge-based economy plays in causing climate change. Since most of the studies concentrate on either economic growth or environmental policy alone, there are limited comparative studies between Asian emerging and G-7 nations. The novelty of this study is to investigate the influence of knowledge-based economy on climate change. The second novel aspect of this study is the construction of knowledge-based economy index from four pillars, i.e., economic and institutional regime, education and skills, effective innovation system and ICT unlike the extant studies. By offering empirical insights into how KBE affects climate action in various economic circumstances, this work fills these gaps.

Methodology

Data and Variables

This study employs yearly panel data from 2000 to 2023. The study encompasses 47



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countries selected from Asian emerging nations and G7 advanced countries. With the goal of investigating the link between KE and SDG-13 climate action. The dependent variable of the study is climate change index (KE) measured via two components i.e. annual temperature and per capita greenhouse gases emissions. The main independent variable is knowledge-based economy. The World Bank conceptualizes the knowledge-based economy around four key pillars that enable knowledge to serve as a powerful engine of growth. These include a supportive economic and institutional framework, strong education and skill development, a dynamic innovation system, and robust information and communication technology infrastructure. Several proxies have been adopted for each pillar shown in KE framework. Thus, with the aim of further assessing the various proxies of knowledge-based economy on SDG13 Climate action, the study adopted trade, government effectiveness, and regulatory quality as measurements variables of economic and institutional regime pillar. Adjusted saving on education expenditure and tertiary enrollment as items measuring education and skills pillar. Scientific and technical journal articles are employed as the proxy of efficient innovation system pillar; and internet users and mobile cellular subscriptions as the proxies of ICT pillar (World bank, 2015). The control variables used in the analysis included renewable energy consumption, urbanization and foreign direct investment. The description of variables together with their respective sources is illustrated in Table 1.

Table.1. Description of Variables

Variable	Abbr	Measurement	Source
<p>Climate Change: CC is used as proxy and computed from the following two components:</p> <ul style="list-style-type: none"> i. Annual temperature (Degree Celsius) ii. Per-capita greenhouse gas emissions (Billion tones) 	CC	Index	World bank (2024)
<p>Knowledge Based Economy: KBE index is used as proxy and computed from the following four pillars.</p> <p>a-Economic and Institutional Regime</p> <ul style="list-style-type: none"> i. Trade (% of GDP) ii. Govt effectiveness Score (0-1) iii. Regulatory quality Score (0-1) <p>b-Education & Skill Adjusted saving on education expenditure (Current US\$) Tertiary enrollment (% of gross enrollment)</p> <p>c-Effective Innovation System</p> <ul style="list-style-type: none"> i. Scientific and technical journal articles (Numbers) <p>d-Information and Communication Technology infrastructure</p> <ul style="list-style-type: none"> i. Internet users (% of population) ii. Mobile cellular subscription (Per 1000 pop) 	KE	Index	World bank (2024)
Renewable energy consumption	RE	(% of total final energy)	World bank



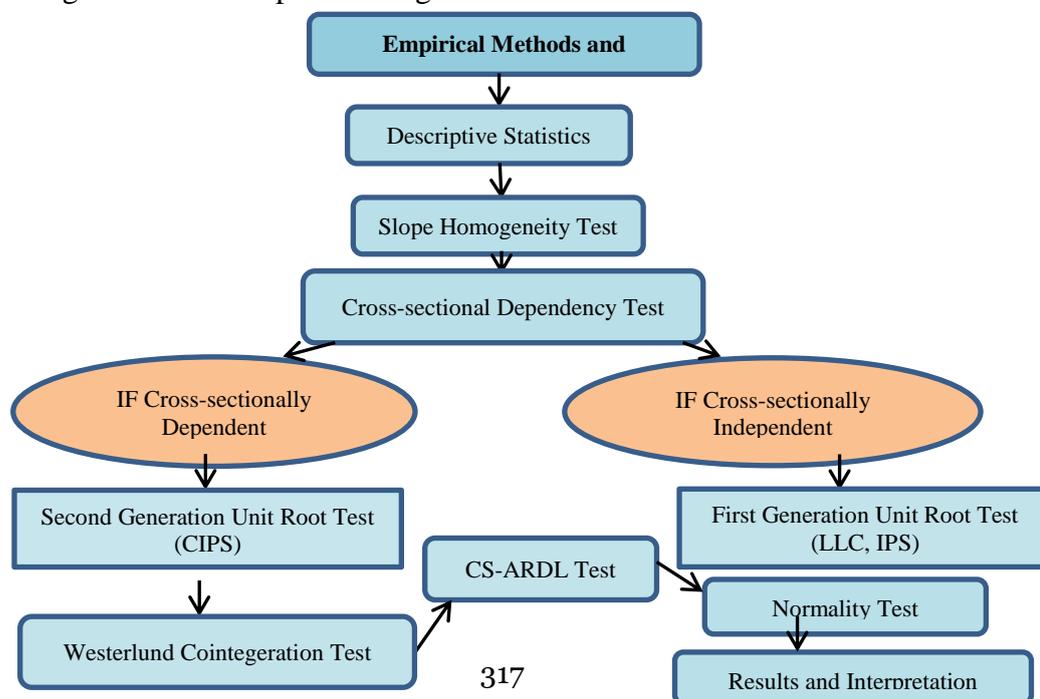
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		consumption	(2024)
Urbanization	URB	(% of total population)	World bank (2024)
Foreign Direct Investment	FDI	net inflows (% of GDP)	World bank (2024)

$$\ln CC_{it} = \beta_0 + \beta_{1it}KE_{it} + \beta_{2it}RE_{it} + \beta_{3it}UP_{it} + \beta_{4it}FDI_{it} + \epsilon_{it} \quad (1)$$

Where i denote the cross-sectional unit or country, t denotes time period 0, 1, 2, 3, 4 and $\beta_0, \beta_1, \beta_2, \beta_3$ and ϵ_{it} denotes intercept, slopes or coefficients of each variable and error term, respectively. The reasons for adding these variables in the model and their expected relation with climate change are explained below:

The econometric analysis goes through several stages. The first stage is performing pre-estimation tests, i.e., cross-sectional dependence tests, to ensure the presence of cross-sectional dependence among the cross sections, prior to assess the stationarity of variables/series followed by slope homogeneity (Ryan et.al. 2024). Regression models for parameter estimation and hypothesis testing must include stationary series with constant mean, variance, and covariance. Including non-stationary series causes spurious regression, which produces deceptive results (Dreger & Herzer, 2013). Researchers frequently use first-generation panel unit root tests to assess the stationarity of series in panel data. These first-generation panel unit root tests are based on the assumption of cross-sectional independence, which means that the cross sections are not correlated (Rasheed et al., 2023). However, in reality, cross-sectional units are correlated and interdependent due to unobserved common factors, violating the basic assumption of first-generation unit root tests (Rafique et al., 2024). The CS-ARDL model is not suitable when a data series is integrated of order two, $I(2)$, as the model is designed for variables that are either stationary at level $I(0)$ or first difference $I(1)$. Researchers should consider alternative models like the Johansen Cointegration Test or Vector Error Correction Model (VECM), which are specifically designed for higher-order integrated series. The methodological frame is depicted in figure 1 as under.





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Therefore, the Pesaran (2007) cross-sectional dependence test, specified in equation 2, was employed to examine the cross-sectional dependence in all series of this study.

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

T represents the duration of the time, whilst N indicates the sample size. Here, $\hat{\rho}_{ij}$ is the correlation error of units, which is presented as follows.

$$\hat{\rho}_{ij} = \frac{\sum_{t=1}^T e_{it}e_{jt}}{(\sum_{t=1}^T e_{it}^2)^{1/2}(\sum_{t=1}^T e_{jt}^2)^{1/2}} \quad (3)$$

Here, $\hat{\rho}_{ij}$ is the correlation between error terms.

The results of the CD test confirm the presence of cross-sectional dependence. Therefore, to address the issue of non-stationarity and identify unit roots in each series, the study employed the CIPS second-generation unit root test, as specified in equation 4.

$$CIPS(N, T) = \bar{T} = N^{-1} \sum_{i=1}^N (N, T) \quad (4)$$

Although the presence of cross-sectional dependence in the residuals does not make traditional fixed and random effects estimators inconsistent, it can reduce their efficiency that lead to biased standard errors. However, when the unobserved common factor driving cross-sectional interdependence is correlated with the explanatory variables, both fixed and random effects estimators become inconsistent as well as inefficient (De Hoyos & Sarafidis, 2006).

Establishing variable stationarity is a prerequisite for panel cointegration and causality tests. This study utilizes the CIPS panel unit root test. Second-generation panel unit root test to confirm the stationary properties of the series (Merdan,2024). The reliability of such tests diminishes significantly in the presence of cross-sectional dependence. A second-generation test was then applied to examine the unit root null hypothesis.

The study employed the second-generation cross-sectional autoregressive distributed lag model, as proposed by Chudik and Pesaran (2015), to examine long- and short-run relationships. This model is utilized for its ability to estimate long-run common coefficients in interdependent country data. It contributes to robust outcomes by accounting for data symmetries and avoids result biases, particularly for large sample sizes and time periods. This approach is advantageous as conventional FMOLS and DOLS methods are insufficient for these specific problems, making the cross-sectional autoregressive distributed lagged model suitable for further estimation. The mathematical expression for the CS-ARDL model is,

$$\begin{aligned} \log CC_{it} = & \partial_0 + \sum_{p=1}^{n1p} \delta ip \log CC_{i,t-p} + \sum_{p=0}^p \delta 1p \log KE_{i,t-p} + \sum_{p=0}^p \delta ip \log RE_{i,t-p} + \\ & \sum_{p=0}^p \delta ip \log URB_{i,t-p} + \sum_{p=0}^p \delta ip \log FDI_{i,t-p} + \sum_{p=0}^p \delta ip \log CC_{i,t-p}^{\leftarrow} + \\ & \sum_{p=0}^p \delta ip \log KE_{i,t-p}^{\leftarrow} + \sum_{p=0}^p \delta ip \log RE_{i,t-p}^{\leftarrow} + \sum_{p=0}^p \delta ip \log URB_{i,t-p}^{\leftarrow} + \\ & \sum_{p=0}^p \delta ip \log FDI_{i,t-p}^{\leftarrow} + \epsilon_{i,t} \quad (5) \end{aligned}$$

In the above equation, ∂_0 is the intercept, is the slope coefficient, and it is the error term, where i represents the cross-sectional units. T shows time series, similarly,

$$\sum_{p=0}^p \delta ip \log CC_{i,t-p}^{\leftarrow} + \sum_{p=0}^p \delta ip \log KE_{i,t-p}^{\leftarrow} + \sum_{p=0}^p \delta ip \log RE_{i,t-p}^{\leftarrow} + \sum_{p=0}^p \delta ip \log URB_{i,t-p}^{\leftarrow} + \sum_{p=0}^p \delta ip \log FDI_{i,t-p}^{\leftarrow}$$

represents the CS part of the model.



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Dumitrescu and Hurlin devised the causality test that was employed in the research (Dumitrescu & Hurlin, 2012). In this study, the variables must be converted from the level to the first difference form because the test was designed for stationary data. Although the coefficients were time invariant, they were permitted to vary across panel members (i.e., the test is relevant for the heterogeneous balanced panels). In the Pairwise Dumitrescu Hurlin penal causality test, the null hypothesis proposes the absence of a causal link among the variables, while the alternative hypothesis asserts the presence of such a relationship. For this purpose thumb rule is applied which means if the probability value is less than 5% level of significance, the null hypothesis is rejected. If the probability value is greater than 5% level of significance accepts the null hypothesis that there is no causal relationship among the variables (Trofimov, 2024).

Results and Discussion

This study empirically and comparatively examined the impact knowledge based economy on climate change for Asian developing and advanced G7 nations. The descriptive statistics of the data series used in the study, such as the mean, median and standard deviation are given in table 2. The mean value of the dataset represents its central tendency. Standard deviation is a statistic that quantifies the extent to which data diverges from the mean. A smaller standard deviation number implies that the dates are concentrated around the mean value. Furthermore, it ensures that the statistical results are reliable and efficient (Khan et al., 2021). A comparison of descriptive statistics between Asian developing countries and the G7 indicates significant structural and developmental gaps across all categories. Asian developing countries have much higher climate change indicators (CC) (mean = 3.06) than G7 countries (mean = 1.19), indicating increased environmental stress.

Table 2. Descriptive Statistics

Asian Developing countries					
Variable	CC	KE	RE	URB	FDI
Mean	3.06	5.50	21.29	1.70	1.55
Minimum	0.06	0.05	0.01	1.12	0.04
Maximum	6.45	10.09	93.46	2.00	10.34
Std. Deviation	1.19	2.34	26.28	0.21	3.70
Variable	CC	KE	RE	URB	FDI
G7 Countries					
Mean	1.19	12.15	3024.79	1.89	0.14
Minimum	0.02	11.55	364.78	1.82	0.06
Maximum	2.54	13.01	8786.12	1.96	12.67
Std. Deviation	0.69	0.33	2954.67	0.32	2.15

In contrast, the knowledge economy index reveals a significant disparity, with G7 nations having significantly more sophisticated knowledge-based economic structures (mean = 12.15) than Asian equivalents (mean = 5.50).

Renewable energy use emphasizes this divide: G7 nations have very high average renewable energy values (mean = 3024.79), albeit with substantial fluctuation, whereas Asian developing countries have far lower and more unequal renewable adoption (mean = 21.29). Urbanization trends also vary across the two groups. G7 nations exhibit consistently high and stable urbanization levels, which correspond to their advanced and well-established infrastructure systems. In contrast, foreign direct investment (FDI) displays a different



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pattern: Asian developing economies record higher average FDI inflows but experience considerable volatility, whereas G7 countries receive relatively lower inflows with much steadier movements over time. Overall, the comparison highlights that G7 economies possess more robust knowledge-based and renewable-energy characteristics, while Asian developing countries continue to encounter stronger environmental challenges and more unstable economic inflows.

Table 3 shows the findings of slope homogeneity. The slope homogeneity results highlight clear structural differences between Asian developing economies and the G-7. For the Asian developing group, both Δ and adjusted $\tilde{\Delta}$ statistics (10.37 and 12.06) are highly significant ($p = 0.00$), indicating strong rejection of slope homogeneity. This shows that the impact of knowledge-based economic factors on climate action differs widely across these countries, reflecting variations in institutional strength, technological readiness, innovation capacity, and environmental policy frameworks.

In contrast, the G-7 group shows much smaller Δ (2.145) and adjusted $\tilde{\Delta}$ (2.51) values, although still significant at the 1% level. This suggests limited but present heterogeneity, with overall more consistent relationships between knowledge-based economy indicators and climate change. The relative uniformity reflects similarities in advanced technologies, strong institutional frameworks, and stable food systems across G-7 countries. Overall, slope heterogeneity is considerably stronger in the Asian developing economies, implying uneven responsiveness of climate change outcomes to improvements in knowledge-based economy drivers. Meanwhile, G-7 nations display more aligned patterns, consistent with their mature innovation systems.

Table 3 The results of slope homogeneity

	Developing Nations		G7 Countries	
Δ	10.37	0.00	2.145	0.00
$\tilde{\Delta}$ adjusted	12.06	0.00	2.51	0.00

Table 4 shows that all the variables have CSD at a 1% level. According to table 4, the results of the CSD test authenticate the existence of CSD and accept the alternate hypothesis as the p-values of each test for all variables are less than 0.01. The CSD results also reveal substantial variation in interdependence between Asian developing economies and the G-7 group. Among the Asian developing countries, the CD-test statistics are notably high—for example, knowledge economy (KE = 131.31**), urbanization (URB = 120**), and climate-related indicators (CC = 77.15**), all significant at 1%. These elevated statistics point to strong cross-sectional dependence, implying that shocks, policy changes, or environmental pressures in one country tend to transmit to others. Such interconnectedness is consistent with shared regional vulnerabilities, comparable development constraints, exposure to environmental risks, and reliance on similar external technological resources. In contrast, the G-7 countries display much lower CD-test statistics, indicating only moderate cross-sectional dependence. Although variables such as KE, RE, and URB remain significant, their values are far smaller than those of the Asian developing group, suggesting weaker spillover effects. This reflects the G-7's diversified economies, stronger institutions, and resilient innovation systems, which allow them to absorb shocks with greater autonomy. Overall, the comparison shows that Asian developing countries experience much stronger interdependence, driven by shared structural constraints and vulnerabilities, while the G-7 exhibit more contained and manageable dependence.

Table 4. The results of the Cross-sectional Dependence Test.



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Asian Developing countries					
	CC	KE	RE	URB	FDI
CD-test	77.15**	131.31**	4.06**	120**	18.10**
P-value	0.01	0.01	0.01	0.01	0.01
G-7 Countries					
CD-test	0.89**	15.40**	17.76**	20.67**	3.34**
P-value	0.01	0.01	0.01	0.01	0.01

**explains 1% significance level.

This necessitates further examination of the stationarity properties while accounting for cross-sectional dependence. The findings of CIPS for all the aforementioned variables are given in tables 5 and 6 for both developing and advanced G7 countries. It is found that data for climate action, knowledge-based economy, renewable energy consumption; urban population and foreign direct investment are integrated at first difference. When testing for unit roots in panel data, the existence of cross-sectional dependence requires the application of tests that account for this feature. Traditional first-generation unit root tests are unsuitable under CSD. Hence, second-generation approach CIPS was employed to examine the stationarity of each series. Table 5 and 6 reports the CIPS panel unit root results for Asian developing countries. Across all variables CCI, KEI, RE, UP, and FDI the test statistics at level are higher than the corresponding critical values under both specifications (constant and trend), indicating non-stationarity. However, at the first difference, all variables show CIPS values that are more negative than the critical values. This confirms stationarity after differencing. Thus, each variable is integrated of order one, I(1), regardless of whether the model includes a constant only or both trend and constant.

Table 5. Results of CIPS for Asian Developing Nations

	At Level		At First Difference		Result	At Level		At First Difference		Result
	Constant		Constant			Constant		Constant		
Variables	CIPS Value	C-Value	CIPS Value	C-Value		CIPS Value	C-Value	CIPS Value	C-Value	
ICCI	-1.33	-2.33	-6.01	-2.33	I(1)	-2.67	-2.86	-6.13	-2.86	I(0)
IKEI	-1.95	-2.33	-4.48	-2.33	I(1)	-2.65	-2.86	-4.37	-2.86	I(1)
IRE	-1.28	-2.33	-3.77	-2.33	I(1)	-1.30	-2.86	-4.09	-2.86	I(1)
IUP	-1.50	-2.33	-3.02	-2.33	I(1)	-2.08	-2.86	-3.16	-2.86	I(0)
IFDI	-2.20	-2.33	-5.60	-2.33	I(1)	-1.06	-2.86	-5.64	-2.86	I(0)

Table 6. Results of CIPS for G7 Countries.

	At Level		At First Difference		Result	At Level		At First Difference		Result
	Constant		Constant			Constant		Constant		
Variables	CIPS Value	C-Value	CIPS Value	C-Value		CIPS Value	C-Value	CIPS Value	C-Value	
ICCI	-1.99	-2.11	-5.76	-2.11	I(1)	-2.33	-2.61	-5.84	-2.61	I(1)
IKEI	-3.14	-2.11	-5.05	-2.11	I(1)	-2.44	-2.61	-5.13	-2.61	I(1)
IRE	-1.01	-2.11	-4.28	-2.11	I(1)	-2.13	-2.61	-4.42	-2.61	I(1)



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IUP	-0.22	-2.11	-2.23	-2.11	I(1)	-1.20	-2.61	-2.26	-2.61	I(1)
IFDI	-2.08	-2.11	-5.18	-2.11	I(1)	-2.59	-2.61	-5.21	-2.61	I(1)

The Westerlund (2007) cointegration test was employed to examine the existence of a long-run equilibrium relationship among the selected variables across the panel. This test is particularly suitable for heterogeneous panels with potential cross-sectional dependence, as it is based on error-correction dynamics rather than residual stationarity (Abdellah, 2025). Therefore, the findings confirm that the variables move together in the long run, supporting the assumption of a stable equilibrium association among knowledge-based economy indicators and climate action measures. Overall, the results demonstrate that both panels exhibit long-run cointegration, implying that the variables move together over time despite short-run fluctuations, with stronger adjustment dynamics observed in the Asian developing nations.

Table 7. The results of Westerlund cointegration.

	Asian developing nations		G-7 Advanced Nation	
	Statistics	P-value	Statistics	P-value
Variance Ratio	-3.97	0.01	-2.42	0.01

In the second phase of panel econometric analysis, the study examined the cointegration was then tested using Westerlund method. As all variables in the current study were stationary at first difference. Hence Westerlund penal cointegration test is applied. Therefore, the co-integration relationship is verified. The research will continue with the determination of the model type. CS-ARDL is applied to check the long run and short run relationship among the variables.

In case of developing nations, the p-value of IKE is 0.05 showing higher significance at 5% with coefficient value -0.20. This means that in the long-run, ceteris paribus, a 1% rise in KE leads to a 0.20% reduction in climate change. At 5% significance level, the KE's short-term coefficient value is -0.26 which is statistically significant. This indicates that for every 1% rise in knowledge based economy, climate action decreases by 0.26%. The outcomes are in line with the work of Chen and Lee (2020), who claimed that technological innovation in high-income countries effectively reduces CO2 emissions. Newer and cleaner technologies gradually replace the outdated, polluting ones as the economy expands (Saboori et al., 2017). KE capacity building is essential for any economy aims to endure and thrive among the challenges of the modern economy. While expecting that different pillars of knowledge-based economy catalyze the achievement of climate action (Bohlinger and Hummel, 2024). While considering the parameter values of advanced G7 nations, the probability value of IKE is <0.01 showing higher significance at 1%. Coefficient value of IKE is -3.79. This means that in the long-run, ceteris paribus, a 1% rise in KE leads to a 3.79% reduction in climate change. At 1% level of significance, the KE's short-term coefficient value is -1.82. This indicates that for every 1% rise in KE, climate action decreases by 1.82%. These results are in line with research by Ali et al. (2023) and Bloomfield et al. (2018), which asserted that KE initiatives can help create climate resilience.

For developing nations, the renewable energy with a p-value of 0.004 and a coefficient value of -0.35 is statistically significant at 1%. Ceteris paribus, a 1% increase in RE over time leads to a 0.35% reduction in climate change. The usage of renewable energy has a short-term coefficient value of -0.37, which is statistically significant at 5%. This indicates that for every 1% rise in KBE, climate activity decreases by 0.37. According to



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study of Ito (2017), 42 developing countries have seen a decrease in emissions as a result of renewable energy. According to Bhattacharya et al. (2017), 85 developed and developing economies worldwide have seen a significant decline in climate change as a result of greater usage of renewable energy. In accordance with Zhang and Liu (2019), the development of renewable energy contributes to the environmental improvement of Asian nations. Furthermore, technological advancements enable the economy to meet energy demands by switching from finite to renewable energy sources. Observing the coefficient values of G7 countries, Renewable energy with a p-value of 0.004 and a coefficient value of -0.45 is statistically significant at 1%. Ceteris paribus, a 1% increase in RE over time leads to a 0.45 % reduction in climate change. The usage of renewable energy has a short-term coefficient value of -0.96, which is statistically significant at 5%. This indicates that for every 1% rise in KBE, climate activity decreases by 0.96. A substantial energy shift is necessary to reach the objective of climate-neutral energy systems. Renewable energy sources such as solar, wind, geothermal, biomass, and hydraulic energy are abundant in Turkey (Shan et al., 2021).

Considering the Asian developing countries, the coefficient value of urbanization is 3.21 having positive and significant impact of 0.048 on climate action in the long run. This means that in the long-run, ceteris paribus, a 1% rise in IURB leads to a 3.21% upsurge in climate change. In accordance with results of (Chan et al., 2024), who claimed that increasing frequency and intensity of extreme weather events have further elevated flood risks in delta regions, especially in densely populated and poorly infrastructure areas. In short run, other things remain the same, the coefficient value of urbanization is 5.49 having insignificant impact of 0.05 on climate action. This means that one percent increase in urbanization brings 5.49 % increase in climate change. While in case of advance G7 nations, the coefficient value of urbanization 2.41 having positive and significant impact of 0.05 on climate action in the long run. This means that in the long-run, ceteris paribus, a 1% rise in IURB leads to a 2.41% upsurge in climate change. In short run, other things remain the same, the coefficient value of urbanization is 4.50 having significant impact of 0.05% on climate action. This means that one percent increase in urbanization brings 4.50% increase in climate change. In accordance with the findings of Das et al. (2024), resolving urbanisation and climate change is difficult because of its complicated effects on human well-being and global sustainability. Rapid city expansion, or urbanisation, raises energy usage.

The coefficient value of foreign direct investment is -0.024 in case of Asian developing nations. The coefficient having negative and significant impact of 0.048 on climate change in the long run. This means that in the long-run, ceteris paribus, a 1% rise in FDI leads to a 0.024% decrease in climate change. In short run, other things remain the same, the coefficient value of FDI is 0.0102% having positive and significant impact of 0.061% on climate change. This means that one percent increase in foreign direct investment brings -0.0102 % rise in climate change in line with studies of (Tang and Tan, 2015), whose results shows that FDI positively impact the environmental quality in Vietnam. Taking the scenario of developed G7 economies, the coefficient value of foreign direct investment -0.050 having negative and significant impact of 0.005 on climate change in the long run. This means that in the long-run, ceteris paribus, a 1% rise in FDI leads to a 0.050% increase in climate change. In short run, other things remaining the same, the coefficient value of FDI is 0.053% having positive and insignificant impact of 0.761% on climate change. This means that one percent increase in foreign direct investment brings -0.053 % rise in climate change. Aligned with research by Zhang and Zhou (2016), who looked at the relationship between foreign direct investment and environmental



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degradation in China and came to the conclusion that FDI reduces environmental damage while industrial structure and equipment level reduce environmental pollution in China. Furthermore, the error correction term for developing nations indicates that the model is dynamically stable, which means that short-term disequilibrium is eliminated over time. For the persistence of dynamic stability, the ECT coefficient value must be negative and significant. In the results, the coefficient value of the error correction term is -0.97. While in case of G7 economies analysis, the error correction term value is -0.89 with p-value <0.01 which absolutely parallels to the first assumption of a significant negative ECT term at 1%

Table 8. Result from CS-ARDL Estimation.

	Asian developing nations		Advanced G-7 countries	
Long run				
Variables	Parameters	Std.Error	Parameters	Std.Error
like	-0.20**	0.09	-3.79**	1.50
IRE	-0.35**	0.19	- 0.45**	0.13
IURB	3.21*	14.98	2.41**	7.01
IFDI	-0.02 **	0.01	-0.05**	0.02
Short Run				
D(IKE)	-0.26**	0.13	-1.82**	0.88
D(IRE)	-0.37**	0.21	-0.96**	0.44
D(IURB)	5.49**	11.02	4.50**	7.25
D(IFDI)	0.01**	0.05	0.05**	0.17
ECT	-0.97**	0.37	-0.89**	0.10

Note: * and **denote the statistical significance at 1% and 5%.

For our key empirical findings, the study performed a robustness test termed as Pairwise Dumitrescu Hurlin causality test in table 6 for Asian developing and G7 advanced nations accordingly. The empirical evidence shows a bidirectional association between climate change, knowledge-based economy, renewable energy consumption and foreign direct investment. Between climate change and urban population there is unidirectional relationship.

This diagnostic test ensures the robustness of the CS-ARDL model by checking for potential issues like causal relationships and accounts for heterogeneity. The study performed the Dumitrescu–Hurlin causality test on the variables' first differences as a robustness check. Based on estimated standardised Z~ statistics, which are appropriate for panels with a given time-series dimension, the causation direction was determined. Additionally, the standardised Z statistics and the asymptotically well-behaved average Wald (W^-) were provided for comparison. Bi-directional causality is found among the selected variables as probability value is less 5%. Resultantly, alternative hypothesis is accepted.

Table 9. Results from Pairwise Dumitrescu Hurlin causality test.

Asian developing nations			
Causal Direction	W-Stat.	Zbar-Stat.	P value
CC----->KE	4.46	2.18	<0.01
KE----->CC	7.73	2.57	<0.01
CC----->RE	6.34	1.71	<0.01
RE ----->CC	5.50	2.33	<0.01



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CC----->FDI	5.13	3.42	<0.01
FDI----->CC	9.70	7.45	<0.01
CC----->URB	2.40	4.43	<0.23
URB----->CC	6.57	4.29	<0.01
G-7 Advanced Countries			
CC----->KE	2.57	2.23	<0.01
KE----->CC	3.21	5.23	<0.01
CC----->RE	3.87	4.34	<0.01
RE ----->CC	6.33	4.43	<0.01
CC----->FDI	2.37	1.92	<0.01
FDI----->CC	9.72	7.45	<0.01
CC----->URB	4.02	4.44	<0.95
URB----->CC	3.35	3.25	<0.01

Conclusions and Recommendations

The 13 Sustainable Development Goal Climate action has been one of the most important problems that mankind has faced in recent decades. Through an empirical comparison of emerging South Asian countries and the G-7 countries, this study has investigated how the KE impacts SDGs. The empirical findings indicate a significant disparity between the two groups of countries, largely driven by differences in investment KE. The findings of the study demonstrated a negative and substantial correlation between KE and climate change for developed as well as emerging nations over the short and long term. The relationship between climate change and the consumption of renewable energy and FDI and climate change is detrimental and substantial for both groups of nations. The findings demonstrate a positive and remarkable relationship between the urban population and climate change.

The results demonstrate that G-7 countries, with their advanced knowledge infrastructures, high levels of technological innovation, and robust institutional frameworks, are better positioned to integrate KE principles into climate action policies. In these economies, high expenditures on R&D, collaboration between academia and industry, and stringent environmental policies have fostered the transition toward a low-carbon economy. Conversely, Asian developing countries, despite recognizing the transformative potential of the knowledge-based economy, face structural constraints that hinder their ability to leverage KE for climate action effectively. Limited financial and technological resources, gaps in skilled human capital, weak policy implementation, and a reliance on traditional, carbon-intensive industries pose significant challenges. For Asian nations, targeted investments in education, technology transfer mechanisms, and research collaboration are essential. In conclusion, the knowledge-based economy is a key enabler of climate action, but its impact is contingent on economic, institutional, and technological readiness. The disparities observed between G-7 nations and South Asian developing countries highlight the need for targeted policy interventions, increased investment in green economies, and enhanced international cooperation. Strengthening knowledge-driven approaches in developing economies can significantly enhance their climate resilience and contribute to global sustainability efforts.

The following are some suggestions made by the authors for businesses looking to participate in the KE activities to mitigate climate change effects. Hence meet SDG-13 climate action. Training young people to be change agents in their communities has a lot of potential in some situations. After training opportunities, follow-up assistance is crucial to aid participants in reaching their objectives. Monitoring initiatives should be



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utilised to assess the tools and strategies of the knowledge-based economy and to manage the programs in an adaptable manner over time. More research should be done in this area. The economic and institutional regime play an important role in improving policies regarding climate action. Therefore government should keep check and balance on policies. Need to introduce and adopt more renewable energy resources ways. Urbanisation is good but should be done with proper care without harming environment. The foreign direct invest should be designed in such a way that is eco-friendly. All these recommendations are pure result based.

Limitation and Future Research

This research contains a few restrictions. The study's robustness is deemed sufficient and has achieved a considerable level. Data availability constraints, differences in national policy frameworks, and the varying pace of digital transformation across countries may affect the generalizability of findings. However, this study analyses the aggregate impact of KE on climate change, other researcher may analyses the individual impacts of each pillar of knowledge base economy. Despite Asian developing and advanced G7 countries, future researcher may use other regions or single countries for the same objective. Future research should explore sector-specific contributions of KE to climate action, assess the part of evolving technologies such as artificial intelligence, blockchain, and the Internet of Things (IoT) in climate governance, and examine the socio-economic implications of transitioning to a knowledge-driven sustainable economy in developing nations. In summary, the success and realisation of the SDGs will be greatly influenced by the knowledge-based economy, and we hope that the compilation of studies offered here will be a useful manual for creating the various KE projects needed to achieve the SDG 13th climate action. Furthermore, interdisciplinary approaches integrating economic, environmental, and technological dimensions can offer deeper insights into optimizing the knowledge-based economy's role in climate resilience.

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