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Impact of energy innovation on greenhouse gas emissions: Moderation of regional integration and social inequality in Asian economies

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ADB Working Paper Series

**IMPACT OF ENERGY INNOVATION ON
GREENHOUSE GAS EMISSIONS:
MODERATION OF REGIONAL INTEGRATION
AND SOCIAL INEQUALITY
IN ASIAN ECONOMIES**

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Abstract

In order to reduce greenhouse gas (GHG) emissions and to achieve the Sustainable Development Goals (SDGs), Asian countries are trying to realize the potential of energy innovation. However, several structural issues might deter the expected impact of energy innovation on GHG emissions. Given the ecologically unsustainable economic growth trajectory of Asian countries, achieving the full potential of energy innovation is necessary, and therefore an efficient development and diffusion of these solutions requires a policy reorientation. Given the present situation of Asian countries in attaining SDG objectives, there is a void in the academic literature in terms of a policy framework, and there lies the contribution of the present study. This study aims to shed light on how regional integration and social inequality can moderate the desired environmental impact of energy innovation. Based on the outcomes of the study conducted on 24 Asian countries over the period 1990–2019, this study has recommended a multipronged SDG-oriented policy framework. This policy framework is developed by considering the internal and external structural issues with Asian countries, and, using a phase-wise policy implementation approach, a way to address the objectives of SDGs 7, 9, and 13 is discussed.

Keywords: energy innovation, GHG emissions, Asia, regional integration, social inequality

JEL Classification: Q48, Q53, Q55, Q56

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1. INTRODUCTION

Climate change is the reason behind most of the environmental hazards in recent decades. The global average temperature today is 1 degree Celsius higher than in pre-industrialization times with many regions witnessing even higher warming levels. Nearly 40% of the world's population resides in areas that remain 1.5 degrees Celsius warmer than the pre-industrial level. This has worsened the existing economic, environmental, and social problems with disruptive implications for the future. The 17 Sustainable Development Goals (SDGs) adopted by member states of the United Nations in 2015 also call for protection of the planet and are aimed at ensuring environmental sustainability. While all the SDGs are integrated with each other, with action towards one goal resulting in a change in outcome in the other SDGs, Goal 13 specifically aims to "take urgent action to combat climate change and its impact" and calls for adoption of a holistic approach to climate action. Policymakers in the energy domain are increasingly faced with the challenges posed by climate change as it impacts the overall ecosystem and the economic system, the size of which is difficult to predict for climate scientists (IPCC 2014a). The problem of climate change is driven by greenhouse gas (GHG) emissions, which are the result of a gradual increase in economic activities (Bekun, Emir, and Sarkodie 2019). While energy fuels our economies as a key input for transportation, industrial production, and consumption by households in the form of fuel or electricity, excessive energy use also raises the level of GHG emissions, leading to climate change. The Energy Technology Perspectives 2020 report by the International Energy Agency (IEA) suggests that about one-third of GHG emissions are caused by industrial, agricultural, and allied activities and the remaining two thirds by the use of fossil fuels. While there is an inexorable rise in energy demand globally, the growth in energy use was slower than growth in GDP during the period 2000–2019, particularly in emerging economies, because of structural economic shifts and gains in efficiency across the globe (IEA 2020). Despite that, global energy-related CO₂ emissions increased more than 2.5 times between 1970 and 2020. A report by the Intergovernmental Panel on Climate Change (IPCC 2018) demonstrates that global warming needs to be limited to 1.5 degrees Celsius by the end of this century, failing which the world will witness irreversible and catastrophic implications. In other words, carbon dioxide (CO₂) emissions need to be reduced by around 45% by 2030 and reach net zero by 2050. The 2019 Climate Action Summit also reinforced the same targets, highlighting the need for immediate steps to define the short-term (2020) and mid-term (2030) concrete commitments by countries across the globe. Such a sharp fall in CO₂ emissions calls for unconventional measures aimed at social and economic transformation.

As the world attempts to move towards more sustainable and low-carbon practices, energy innovation is emerging as a key enabler in reducing GHG emissions (Gallagher, Holdren, and Sagar 2006; Anadon et al. 2011). Energy innovation at its current pace has not been able to develop technologies that can limit global warming at the desired level. Consequently, more concerted efforts in the direction of energy innovation and large-scale deployment of sustainable energy technologies are the need of the hour. It is well recognized that policies are to be designed in such a way that they create greater demand for clean energy and also attract investment in energy innovation (Anadon et al. 2011; Grubler et al. 2013). However, studies on the relationship between energy technology and GHG emissions have suggested two different explanations. One, which is more popular, suggests that innovation in energy technology reduces GHG emissions. Countries with increased investment in research and development (R&D) and energy innovation witness an acceleration in the adoption of green energy

practices (Zhang et al. 2017). Energy innovation is also associated with improved efficiency and reduced energy generation cost (Mohsin et al. 2018, 2019). Another explanation suggests that the rebound effect prevents energy innovation from having its full effect on carbon emissions reduction. They argue that energy innovation does increase efficiency and reduces the effective unit price, however it also results in increased use of energy services as these become more affordable than before (Dogan and Turkekul 2016; Moutinho et al. 2018).

In a globalized world, economic integration across countries also raises important concerns over climate change. Economic integration coupled with trade liberalization leads to a sharp increase in cross-border transactions through trade, investment, and integrated global value chains. This, on the one hand, has enhanced the overall growth prospects of the participating countries and regions; on the other hand, it has also raised environmental concerns. Trade-led growth can directly impact the environment through increased pollution levels and natural resource degradation. The *pollution haven hypothesis* states that in the absence of stringent preventive policies, countries tend to specialize in pollution-intensive activities and amplify the problem of climate change. Conversely, trade-led growth may also support development and welfare initiatives and provide access to environment-friendly production technologies, enhancing the capacity of nations to deal with environmental concerns more effectively.

Moreover, climate change affects the poor more adversely than the rich (IPCC 2014b). The most affected population includes those who are socially and geographically disadvantaged. Rising inequality not only increases the exposure of people to climate hazards, but their susceptibility to such damage increases and their ability to fight and recover decreases (Islam and Winkel 2017). It is well documented that climate change adversely affects the agriculture sector (Ahmed, Diffenbaugh, and Hertel 2009; Müller et al. 2011), which provides employment to most of the poor population across developing economies. Studies have also documented the channels through which climate change affects the poor, which include prices, asset value, productivity, and availability of opportunities (Hallegatte et al. 2014). Not only does climate change affect inequality, inequality also has its effects on climate change. It works like a vicious cycle where inequality has a feedback effect on climate change, which makes it more worrisome. The per capita waste generation, water consumption, and fish and meat consumption are higher in countries with higher inequality levels. This results in reinforcement of the vicious cycle between inequality and climate change.

Asia provides a good case to study as the region has demonstrated phenomenal economic growth in recent decades. Since the 1970s, the People's Republic of China (PRC) and other Asian countries have witnessed impressive growth rates due to the rising population, urbanization, and industrialization, which has immensely contributed to the rising energy demand in the recent past (Meng et al. 2019). Additionally, the growing regional economic integration has resulted in increased cross-border transactions among Asian countries through trade, investment, and regional value chain channels. The latest Asia-Pacific Regional Cooperation and Integration Index (ARCI) indicates the deepening regional integration of Asia. The regional integration in Asia demonstrated a steady pace from 2006 to 2017. Following a slip in 2017, the index rose in 2018, indicating an overall increase in regional integration for most subregions.

There was a significant increase in energy demand among emerging Asian economies from around 15% of global energy demand in 1970 to 36% in 2019. With the rising energy demand, the emerging economies of Asia have been the largest contributors to the global GHG emissions growth in the past two decades, with the PRC accounting for about two thirds of the increase in global emissions between 2000 and 2019 and the

remaining emerging economies accounting for another 25% of the global emissions during the same period. In the absence of appropriate policies and proactive measures, Asia is expected to witness severe socioeconomic impacts from climate change. Asian economies are more vulnerable to risks posed by climate change as the region contains a number of low-lying coastal cities and experiences episodes of extreme heat and humidity as well as extreme precipitation in some areas, and drought in others. With such diversity in the exposure to climate risk, the growth experience of the region may not be sustainable. Not only is the region's growth unsustainable, but it is also unequal. Over the past two decades, many countries in the region have witnessed the income share of the poorest 20% falling behind the income shares of their wealthiest counterparts with rising cases of malnutrition and child mortality rates. The overdependency of the region on natural resources and the resulting environmental issues have further aggravated the social issues in the region, making the life of the poor even more difficult. There have been instances of poor people drinking polluted water and eating unsafe food, and also land appropriation for the sake of extraction of resources and infrastructure development.

The discussion so far suggests that while energy technology innovation affects the level of GHG emissions in a region, the increased economic integration and inequality level also have an effect on these emissions, which may strengthen or weaken the association between innovation and GHG emissions. The present work thus attempts to analyze the impact of energy innovation on GHG emissions across Asian countries and how regional economic integration and social inequality moderate such an impact. The Asian economies are lagging behind in realizing the SDG objectives, and energy innovation is visualized as a major driver in this realization. Hence, a policy realignment is necessary in these nations, so that the energy innovation can reach its full potential in reducing GHG emissions. This policy realignment might entail social, political, and trade aspects of the policy development, and there lies the focus of the present study. By means of analysis, the present study aims to recommend an SDG-oriented policy framework to assist Asian countries in realizing the objectives of SDG 7 (affordable and clean energy), SDG 9 (industry, innovation, and infrastructure), and SDG 13 (climate action). While assisting these countries in attaining these objectives, this framework also takes into account social, political, and trade dimensions, and this consideration makes the policy framework not only robust but also generalizable for other emerging economies finding complications in achieving the SDG objectives and requiring policy realignment. This SDG-oriented pro-ecological policy design, in considering internal and external exigencies, has not been attempted in the academic literature, and there lies the policy-level contribution of the study.

While stating the policy-level contribution of the study, it is also important to remember that politico-economic spillovers link these countries, and this particular interdependence among the countries might lead to estimation issues. Moreover, all the policy instruments might not exert their impacts simultaneously. In order to accommodate these two estimation issues, the present study has employed a cross-sectionally augmented autoregressive distributed lag (CS-ARDL) approach, which is second generation in nature, and therefore can take account of the cross-sectional dependence in the data. This methodological complementarity has ensured the analytical contribution of the study.

The rest of the manuscript is designed in the following manner: Section 2 reviews the literature on the association between energy innovation and GHG emissions, Section 3 outlines the empirical model and the methods, Section 4 discusses the study outcomes, and Section 5 concludes the study with suitable policy recommendations.

2. REVIEW OF LITERATURE

In recent years, countries across the world have recognized the need to promote research and development in the field of the power sector, as the continued usage of nonrenewable energy solutions appears to be a significant cause of the growing air pollution in developed and developing countries (Miranda et al. 2021). By promoting energy innovation, policymakers are aiming to increase energy efficiency and reduce the ecological footprint. The constructive utilizing of industrial wastes (Otieno and Ochieng 2019), developing energy-efficient production processes (Hu et al. 2019), minimizing the usage of natural resources (Wang et al. 2018), widening the scope of renewable energy (Taghizadeh-Hesary, Yoshino, and Inagaki 2019), and generating green infrastructure and a green work environment (Zhang, Xue, and Zhou 2018) are some of the potential areas that energy innovation can complement directly or indirectly. This requires technological upgradation in the field of energy generation. If innovation in the energy sector makes it easier for manufacturing units, service providers, consumers, and policymakers to reduce energy consumption and GHG emissions, then the technological innovation drive can be considered successful. However, it should be mentioned that technological advancement may encourage firms to produce on a large scale, which may widen the scope for energy consumption and, after that, environmental pollution (Balsalobre and Álvarez 2016). Thus, its impact on environmental quality can vary according to the stages of industrial advancement.

The association between GHG emissions and energy innovation is studied both qualitatively and quantitatively. The efficacy of energy innovation in reducing GHG emissions depends on several factors, such as policy frameworks (Romano et al. 2017), types and volume of investment (Jordaan et al. 2017), types of technologies (Kim and Kim 2015), and institutional factors (Feurtey, Ilinca, and Sakout 2016). In the present study, by using the panel of developing Asian countries, we aimed to assess the temporal impact of energy innovation on GHG emissions. In this context, the literature indicates that GHG emissions can be controlled by increasing research and development in the energy sector (Song and Wang 2015; Hussain and Dogan 2021). For example, by carrying eco-innovation as a determinant of carbon emissions, Ding, Khattak, and Ahmed (2021) reported that increased eco-innovation helped control the level of carbon emissions in the G7 countries during the study period. Based on these findings, the study endorsed increasing the investment in green energy-based projects to achieve both economic and environmental goals.

Similarly, in their study, Mensah et al. (2018) recommend increasing the research and development activities in the alternate power sector, because the extensive usage of cleaner energy resources at the industrial and household levels reduced the level of carbon emissions in the 28 OECD countries. While assessing the relationship between green investment and environmental quality, Sinha et al.'s (2021) study observed an inverse association between ecological quality and green investment projects. In other words, the increased financing for cleaner and environment-friendly products gradually fortified the environmental quality in the long run. The study proposed extending the research environment in the manufacturing and energy generation sectors to achieve the proposed sustainable goals of cleaner energy, industrial growth and innovation, and a cleaner environment.

Romano et al. (2017) considered a segregated panel of developed and developing nations to assess the effectiveness of research grants and government policies in renewable energy projects. The study found a significant and direct association between government funding and renewable energy generation in both types of countries. However, the impact of government policies varied significantly across

nations. Therefore, to increase clean energy production and reduce GHG emissions, Jordaan et al. (2017) suggested applying direct and indirect measures. Reichman et al. (2008) and Weyant (2011), in their respective studies, suggested that the following actions elevate the efficiency of energy innovation: (i) increasing the research grants to universities and private labs; (ii) initiating new and target-oriented projects in the energy innovation field; and (iii) increasing the participation of private researchers and labs by providing them with additional funding. The literature provides several instruments for indirect measures to control GHG emissions, such as carbon tax, environmental awareness of the public, incentivization of innovative and cleaner projects and practices, and promoting private players (Reichman et al. 2008; Weyant 2011; Romano et al. 2017). In an economic sense, technology-push and demand-push factors may help improve the environmental quality. The former may directly reduce the production-led GHG emissions, and the latter may increase the need and demand for a cleaner and more hygienic lifestyle (Jordaan et al. 2017).

In other words, technological upgradation may instigate structural changes in the economy and reduce the level of industrial emissions caused by energy combustion (Álvarez et al. 2017). With the increased income level, consumers may prefer high-tech home appliances and products that are more energy-efficient and environment-friendly (Panayotou 2000).

Besides controlling GHG emissions, technological innovation may help in diminishing the ecological footprint in the long run. In this context, the findings of Ke et al. (2020) revealed that increased technological innovation in the 30 Chinese states reduced the level of ecological footprint. However, the association between technological innovation and ecological footprint varied significantly across the states. By considering environment-related innovation and institutional quality as determinants of ecological footprint, Hussain and Dogan (2021) examined the experience of BRICS nations. The study outcomes revealed that the increased investment in environment-related technologies fortified biodiversity in the long run. The study also recommended improving the institutional quality to strengthen the effectiveness of green projects. While exploring the association between eco-innovation and ecological footprint, Roddis (2018) observed that green procedures were found to be more sensitive towards changes in institutional factors in the long run.

Moreover, economic factors such as costs and raw materials in the UK influenced the production of green products. Further, by taking a panel of Asia and the Pacific nations, Sinha, Sengupta, and Saha (2020) explored the association between technological innovation and an environmental index (comprising a wide range of pollutants) from 1990 to 2017. The study findings revealed that increased technological innovation elevated the level of environmental pollution in the long run. Here one can argue that the increased technological advancement might have intensified the usage of nonrenewable energy solutions at the industrial level. Thus, it might have elevated the level of pollution emissions. These nations also need to promote innovation in the energy sector to control the harmful impact of technology-led large-scale industrial production. Otherwise, countries may continue to bear the environmental costs incurred by the large-scale production of the industrial sector.

In the case of developing nations, the impact of energy innovation on GHG emissions requires in-depth examination, as these nations are going through an economic and structural transition. Moreover, a review of the study outcomes reveals that the impact of energy innovation on GHG emissions varies according to the chosen contexts. This nonconvergence of study outcomes indicates that this particular association might be affected by unobservable factors, which might stem from those contexts. Considering these hidden structural conditions, catalyzing the association

between energy innovation and GHG emissions could have led to policy reorientation in those contexts, which is a policy gap in the literature. The present study addresses that policy void by endorsing an SDG-oriented pro-ecological policy design by considering internal and external contingencies. This approach defines the policy-level contribution of the present study in the academic literature.

3. MODEL AND METHODS

3.1 Theoretical Model

Nations realize energy innovation in the form of improvement in energy efficiency or bringing about transformation in the energy sources towards being cleaner. In both cases, energy innovation is expected to reduce the GHG emissions. However, this expected impact of energy innovation on GHG emissions assumes the *ceteris paribus* condition, which needs to be relaxed in a practical policy scenario. Driven by economic contingencies and external sociopolitical shocks, this impact varies. Regional integration between the Asian countries allows the free movement of technologies and raw materials of production, and given the emerging nature of these economies, these technologies generally use fossil fuel-based energy solutions. Given such a condition, the technology transfer among Asian countries might characteristically reduce the environmental impact of energy innovation. At the same time, the integration of Asian countries with other continents allows the transfer of cleaner technologies, which help in enhancing the environmental impact of energy innovation. Now, as these countries are pro-growth in nature, the growth pattern is characteristically noninclusive, because of which the incidence of poverty and income inequality is comparatively higher in these countries than in their developed counterparts. The prevalence of this income inequality can sometimes create a social imbalance, which can be referred to as “social inequality,” and persistence of this social inequality might have a deterring effect on the environmental impact of energy innovation, as citizens from all income levels cannot access its advantages. Under such circumstances, political intervention is necessary to achieve the full potential of energy innovation using GHG emissions, and in this pursuit, the policy regimes should be adaptive to the transitions in the global political scenario. Following this discussion, the functional form of the empirical model is developed as follows:

$$\text{GHG} = f(\text{EI}, \text{PCI}, \text{REGINT}, \text{INTCOP}, \text{SINQ}) \quad (1)$$

Here, GHG refers to the greenhouse gas emissions, EI refers to the energy innovation index, PCI refers to the political constraint index, REGINT denotes regional integration, INTCOP represents the international cooperation, and SINQ is social inequality. For the empirical pursuit, the testable form of the model is as follows:

$$\text{GHG}_{it} = \beta_0 + \beta_1 \text{EI}_{it} + \beta_2 \text{PCI}_{it} + \beta_3 \text{REGINT}_{it} + \beta_4 \text{INTCOP}_{it} + \beta_5 \text{SINQ}_{it} + \varepsilon_{it} \quad (2)$$

To operationalize the moderating impacts of political constraint, regional integration, international cooperation, and social inequality, introduction of the interaction terms in Eq. (2) is necessary. Hence, the interaction-augmented versions of the empirical model are as follows:

$$\text{GHG}_{it} = \beta_0 + \beta_1 \text{EI}_{it} + \beta_2 \text{PCI}_{it} + \beta_3 \text{REGINT}_{it} + \beta_4 \text{INTCOP}_{it} + \beta_5 \text{SINQ}_{it} + \beta_6 \text{EI}_{it} * \text{PCI}_{it} + \beta_7 \text{EI}_{it} * \text{REGINT}_{it} + \beta_8 \text{EI}_{it} * \text{INTCOP}_{it} + \beta_9 \text{EI}_{it} * \text{SINQ}_{it} + \varepsilon_{it} \quad (3)$$

$$\begin{aligned} \text{GHG}_{it} = & \beta_0 + \beta_1 \text{EI}_{it} + \beta_2 \text{PCI}_{it} + \beta_3 \text{REGINT}_{it} + \beta_4 \text{INTCOP}_{it} + \beta_5 \text{SINQ}_{it} + \beta_6 \text{EI}_{it} * \\ & \text{PCI}_{it} + \beta_7 \text{EI}_{it} * \text{REGINT}_{it} + \beta_8 \text{EI}_{it} * \text{INTCOP}_{it} + \beta_9 \text{EI}_{it} * \text{SINQ}_{it} + \beta_{10} \text{EI}_{it} * \\ & \text{REGINT}_{it} * \text{SINQ}_{it} + \beta_{11} \text{EI}_{it} * \text{INTCOP}_{it} * \text{SINQ}_{it} + \varepsilon_{it} \end{aligned} \quad (4)$$

The use of interaction terms in these two empirical models allows the cross-elasticity of GHG emissions with respect to energy innovation to be computed. The impacts in own-elasticity and cross-elasticity terms from Eqs. (2), (3), and (4) can be shown as follows:

$$\frac{\partial \text{GHG}}{\partial \text{EI}} = \beta_1$$

$$\frac{\partial \text{GHG}}{\partial \text{EI}} = \beta_1 + \beta_6 \text{PCI}_{it} + \beta_7 \text{REGINT}_{it} + \beta_8 \text{INTCOP}_{it} + \beta_9 \text{SINQ}_{it}$$

$$\begin{aligned} \frac{\partial \text{GHG}}{\partial \text{EI}} = & \beta_1 + \beta_6 \text{PCI}_{it} + \beta_7 \text{REGINT}_{it} + \beta_8 \text{INTCOP}_{it} + \text{SINQ}_{it} (\beta_9 + \beta_{10} \text{REGINT}_{it} \\ & + \beta_{11} \text{INTCOP}_{it}) \end{aligned}$$

Therefore, it can be seen that the impact of energy innovation on GHG emissions is conditional on the political constraint, regional integration, international cooperation, and social inequality. As social inequality can further hinder regional integration and international cooperation through creating social imbalance in economic systems, in Eq. (3) social inequality is interacted with energy innovation-regional integration and energy innovation-international cooperation interactions. The respective elasticity values are calculated with the respective sample means.

3.2 Data

The study is conducted for 23 Asian countries over the period 1990–2019. The list of 23 countries is provided in Appendix 1. The data for greenhouse gas emissions (GHG) (in metric tons of CO₂ equivalent) have been collected from the Climate Analysis Indicators Tool (CAIT) climate data explorer of the World Resources Institute (2021).

Political Constraint Index data were collected from the Political Constraint Index (POLCON) database developed by Henisz (2017). A higher value of this indicator shows higher political constraint, or in other words, less feasibility in terms of policy change. Following Shah (2020), the data for regional integration are measured by the trade share of each Asian economy in the whole of Asia, and they were collected from the Asia Regional Integration Center of the Asian Development Bank (ADB 2020). International cooperation, on the other hand, is measured by the tax on trade and international transactions, and these data were collected from the International Center for Tax and Development (ICTD) database of the United Nations University (UNU 2020). Lastly, social inequality is measured by the consumption-based Palma ratio, which indicates the share of the top 10% in terms of gross national income divided by that of the bottom 40%, and these data were collected from the Global Consumption and Income Project (GCIP) database (Lahoti, Jayadev, and Reddy 2016). The sample period of the study is contingent upon the availability of data for regional integration.

The Energy Innovation Index was created using Fisher's Ideal Index following Leal and Marques (2019), and the formulation for energy innovation is as follows:

$$\text{EI}_t = \frac{\text{TN}_t}{\text{EO}_t} = \sum_i \left(\frac{\text{TN}_{it}}{\text{EO}_{it}} \right) \left(\frac{\text{EO}_{it}}{\text{EO}_t} \right) = \sum_i \text{SEI}_{it} \text{SCE}_{it}$$

Here, EI_t is composite energy intensity, TN_t and EO_t are total power consumption and economic output at time t , SEI_{it} is sectoral energy intensity, and SCE_{it} is sectoral composition of nation i at time t . Next, calculation of the Energy Intensity Index (ENI) is as follows:

$$ENI_t = \frac{EI_t}{EI_0} = \frac{\sum_i SEI_{it} SCE_{it}}{\sum_i SEI_{i0} SCE_{i0}}$$

Here, i and 0 indicate all the parameters of country i at the base year $t = 0$. In the next step, Laspeyres (LI) and Paasche (PI) indices are calculated:

$$LI_t = \frac{\sum_i SEI_{it} SCE_{i0}}{\sum_i SEI_{i0} SCE_{i0}}$$

$$PI_t = \frac{\sum_i SEI_{it} SCE_{i0}}{\sum_i SEI_{i0} SCE_{it}}$$

Now, to compute the energy innovation at time t , the geometric average of LI and PI is taken:

$$EI_t = 1/\sqrt{LI_t * PI_t} \quad (5)$$

To calculate the energy innovation, the data on GDP per capita were gathered from the World Development Indicators, the data for gross value added by economic activity from the United Nations Statistics Division, and final energy consumption by sector from the International Energy Agency. Table 1 provides a brief description of variables and their respective sources of data.

Table 1: Variable Descriptions

Variable Name	Data Source	Description of Variables
Dependent		
Greenhouse Gas Emission	WRI (2021)	GHG emissions including LUCF
Independent		
Energy Innovation	Author's computation	–
Political Constraint Index	Henisz (2017)	–
Regional Integration	ADB (2020)	Trade Share within Asia (%)
International Cooperation	ICTD (UNU 2020)	Taxes on International Trade and Transactions
Social Inequality	GCIP (Lahoti, Jayadev, and Reddy 2016)	Consumption Inequality – Palma ratio

3.3 Methodology

3.3.1 Cross-sectional Dependence Test

Panel data series, as a combination of time series and cross-sectional data, are data gathered at a particular time from a specified geographical location, which may be dependent, in terms of policy, on one another. Just before embarking on any panel data analysis, the cross-sectional dependence (CD) in the series needs to be taken into consideration (Breusch and Pagan 1980; Pesaran 2004), otherwise there would be wrongful selection of unit root tests, and cointegration techniques in the analysis, and this may result in inconsistent and spurious results (Pesaran, Ullah, and Yamagata

2008). Breusch-Pagan (1980) is the foremost study to test the existence of CD using the cross-sectional dependence Lagrange multiplier (CDLM) among panel data series. But the test is biased because both the group and individual average are not equal to zero, thus Pesaran, Ullah, and Yamagata (2008) make adjustments to the test by including the average and the variance. Hence, the test is called “adjusted CDLM_{adj.}” The null hypothesis of the test is that there is no existence of CD among the sampled countries. The equation of the CD test, according to Chudik and Pesaran (2015), is given below:

$$CD = \left(\frac{TN(N-1)}{2} \right)^{1/2} \bar{P} \quad (6)$$

$$\bar{P} = \left(\frac{2}{N(N-1)} \right) \sum_{i=1}^{N-1} \sum_{j=i+1}^N \widehat{P}_{i,j} \quad (7)$$

where $\widehat{P}_{i,j}$ denotes the pairwise correlation coefficient of the cross-sectional residuals specified from the augmented Dickey-Fuller test (ADF). T is the time series dimension while N is the cross-section series, respectively.

3.3.2 Second-Generation Unit Root Test

After testing for the existence of CD and the null hypothesis is rejected, the series can be subjected to unit root testing to assess for stationarity in the series. The unit root test that takes into account CD dependency is termed the “panel second-generation unit root test” (Moon and Perron 2004; Pesaran 2007), and in this study we will incorporate cross-sectional augmented Dickey-Fuller (CADF) and cross-sectional Im-Pesaran-Shin (CIPS) tests. The econometric equation for the CADF test is expressed in Eq. (8):

$$\Delta z_{i,t} = \Phi_i + \gamma_i y_{i,t-1} + \beta_i \bar{y}_{t-1} + \sum_{i=0}^q \rho_{i,t} \Delta \bar{y}_{it-1} + \sum_{i=0}^q \zeta_{i,t} y_{i,t-1} + \mu_{i,t} \quad (8)$$

where q is the lag length of the variables, and \bar{y}_t estimates the cross-sectional dependency computed from $\bar{y}_t = \frac{1}{N} \sum_{i=1}^N y_{i,t}$ over a period of time t. Furthermore, the CIPS test can be computed from the calculated mean value of the CADF test.

$$CIPS = \frac{1}{N} \sum_{i=1}^N t_i(N, T) \quad (9)$$

The null hypothesis of each test is that the series has a unit root (nonstationary). The series is checked at level and at first difference. If there is evidence of a unit root at the level, then the series is nonstationary, and thus it needs to be difference. If the first difference of the series is stationary, then the series has no unit root, and thus it is integrated of order one (1). Hence, the stationary data can be used to establish the cointegration relationship among the variables.

3.3.3 Westerlund Cointegration Test

After the CD and stationary test, investigation of the long-run relationships of the studied variables is essential, and this will be carried out using panel cointegration techniques. Specifically, in the presence of CD, a robust panel cointegration method developed by Westerlund and Edgerton (2007) is employed. The rationale behind this is that the techniques provide statistical values that ascertain whether the data series have a long-run relationship. The equation for calculating the procedure is given below.

$$\Delta W_{i,t} = \alpha_i T_t + \gamma_i W_{i,t-1} + \rho_i V_{i,t-1} + \sum_{l=1}^{p_i} \gamma_{i,l} \Delta W_{i,t-1} + \sum_{l=-q_i}^{p_i} \beta_i V_{i,t-1} + \mu_{i,t} \quad (10)$$

The equation is expressed with a constant trend if $T_t = (1)$ and no constant trend if it equals (0). However, if it equals (1, t), it is then expressed with both constant and trend. The possibility of dependency among the variables across countries was considered by Pesaran (2007), using Eq. (10), to provide a stationary solution. In doing so, the error term of the procedure is thus calculated.

$$\epsilon_{i,t} = \gamma_i F_t + \mu_{i,t} \quad (11)$$

Estimating the averages of cross-sectional dependency provides the proxies for the F_t , which is the factor matrix in Eq. (11). The proxies are expected to be consistent, so the cross-sectional dependency results would be efficiently managed.

The null hypothesis of the methods suggested that there is no evidence of cointegration. Hence, if the statistical value of each test is greater than the critical value, the null hypothesis will be rejected in favor of the alternative hypothesis, which suggests the presence of a long-run association.

3.3.4 Long-run Estimation

Owing to the association among countries in the continent, this study applies the panel cross-sectional dependence autoregressive distributed lag model (CS-ARDL) developed by Chudik and Pesaran (2015). The CS-ARDL, except for the long period required to produce reliable results (Chudik et al. 2015), has several advantages in comparison to other long-run estimation techniques such as FMOLS, DOLS, and PMG. Firstly, it checks for any problem of cross-sectional dependency. Also, along with long-run estimates, it provides short-run estimates and the average for each target variable; it also has the ability to estimate an endogeneity problem and checks for serial correlation, and even common correlation coefficients. The regression equation for CS-ARDL for this study is estimated using the equation below:

$$\Delta GHG_{it} = \mu_i + \varphi_i (GHG_{it-1} - \beta_i X_{it} - \phi_{1i} \overline{GHG}_{t-1} - \phi_{2i} \overline{X}_{t-1}) + \sum_{j=1}^{p-1} \lambda_{ij} \Delta GHG_{it-j} + \sum_{j=0}^{q-1} \zeta_{ij} \Delta X_{it-j} + \eta_{1i} \Delta \overline{GHG}_t + \eta_{2i} \Delta \overline{X}_t + \epsilon_{it} \quad (12)$$

where j and t denote the dimensions of cross section and time, respectively. ΔGHG_{it} is the dependent variable, X_{it} is all the independent variables of the long-run estimate, \overline{GHG}_{t-1} and \overline{X}_{t-1} are the mean of the lagged dependent variable and matrix of the mean of the lagged independent variables, ΔGHG_{it-j} and ΔX_{it-j} are the lagged dependent variable and matrix of the lagged independent variables in the short run, $\Delta \overline{GHG}_t$ is the mean of the dependent variable, $\Delta \overline{X}_t$ is the matrix of the mean of the independent variables, and ϵ_{it} is the error term.

4. RESULTS AND DISCUSSION

The study first considers the cross-sectional dependence of the variables. The results reveal a significant cross-sectional dependence among the outcome variables of interest, as the null hypothesis of no cross-sectional dependence can be rejected at a 1% level of significance. Hence, further estimation techniques must take account of this cross-sectional dependence. After finding cross-sectional dependence, the study performs second-generation unit root tests such as CIPS and CADF. At the first

difference, the variables become stationary, implying that all the variables are $I(1)$, or integrated to the first order.

Table 2: Cross-sectional Dependence Test Outcomes

	GHG	EI	REGINT	INTCOP	PCI	SINQ
CD statistics	82.406 ^a	26.886 ^a	82.448 ^a	3.836 ^a	47.697 ^a	47.697 ^a
Slope heterogeneity	23.681 ^a	25.804 ^a	22.657 ^a	23.702 ^a	15.538 ^a	24.062 ^a

Notes:

CD statistics are calculated by Chudik and Pesaran (2015).

Slope heterogeneity is calculated by Pesaran, Ullah, and Yamagata (2008).

^a p-value < 0.01.

Table 3: Second-Generation Unit Root Test Outcomes

Variables	CIPS		CADF	
	Level	First Difference	Level	First Difference
GHG	-2.414	-4.526 ^a	-1.688	-3.358 ^a
EI	-1.373	-5.167 ^a	-1.399	-4.401 ^a
REGINT	-1.957	-5.475 ^a	-1.969	-4.356 ^a
INTCOP	-1.224	-5.018 ^a	-1.848	-4.037 ^a
PCI	-1.054	-4.093 ^a	-1.793	-3.071 ^a
SINQ	-1.072	-4.222 ^a	-1.811	-3.515 ^a

Note: ^a p-value < 0.01.

The empirical results for Westerlund's (2007) Cointegration Test are presented in Table 4 under the null hypothesis of no cointegration or long-run association among the series. The robust probability value for this test reveals significance at the 1% level, and thus all four statistics indicate rejection of the null hypothesis and provide evidence for accepting the alternative hypothesis that a long-run relationship exists between the series. This implies that there is long-run cointegration among the variables of this study.

Table 4: Westerlund (2007) Cointegration Test Outcomes

Statistics	Value	Z-value	P-value	Robust P-value
Gt	-1.009	5.605	1.000	0.000
Ga	-3.716	5.001	1.000	0.005
Pt	-5.001	3.291	1.000	0.001
Pa	-2.679	3.228	0.999	0.012

Now we can proceed towards the estimation of CS-ARDL as we have found the cross-sectional dependence in the data. The findings from CS-ARDL for three of our models are presented in Table 5. The individual impacts of the model parameters are captured through Eq. (2) and this version of the model is denoted as Model 1. On the other hand, the interactive effects of the model parameters on the environmental impact of energy innovation are captured through Eqs. (3) and (4), and these two models are denoted as Models 2 and 3. These three models and the respective impacts of the model parameters will be analyzed in the following subsections.

Table 5: Outcomes of CS-ARDL Estimation

Nature of Coefficients	Model Parameters	Model 1	Model 2	Model 3
<i>Long run</i>	EI	-1.4867 ^b	-1.1589 ^a	-1.0266 ^a
	REGINT	0.2132 ^a	0.0276	0.0734 ^a
	INTCOP	-0.3282	-0.5108 ^b	-0.6859
	PCI	0.0628	0.0722	0.1128 ^b
	SINQ	0.1129 ^c	0.1867 ^b	0.2863
	EI * REGINT	–	0.2108	-0.0074
	EI * INTCOP	–	-1.2178 ^a	-1.3778
	EI * PCI	–	0.0236 ^c	0.1535
	EI * SINQ	–	0.6932	0.9458 ^a
	EI * REGINT * SINQ	–	–	0.4812 ^a
	EI * INTCOP * SINQ	–	–	-0.3967
<i>Short run</i>	Δ EI	-0.6712 ^a	-0.6538 ^b	-1.1136 ^a
	Δ REGINT	0.3648 ^a	0.0055 ^c	0.0127
	Δ INTCOP	-0.2805	-0.3461 ^b	-0.3582
	Δ PCI	0.1035	0.3112	0.2259 ^c
	Δ SINQ	0.0877	0.0565	0.0916
	Δ (EI * REGINT)	–	0.3238	-0.1530 ^a
	Δ (EI * INTCOP)	–	-0.2971 ^a	-0.7581
	Δ (EI * PCI)	–	0.2785 ^b	0.1325
	Δ (EI * SINQ)	–	0.2154	0.2754
	Δ (EI * REGINT * SINQ)	–	–	0.9158 ^a
	Δ (EI * INTCOP * SINQ)	–	–	-1.0765

Notes:

^a p-value < 0.01.^b 0.01 < p-value < 0.05.^c 0.05 < p-value < 0.10.

4.1 Discussion of Individual Impacts

According to the Intergovernmental Panel on Climate Change (IPCC), the role of energy innovation in controlling and reducing anthropogenic GHG emissions is increasingly gaining attention among policymakers (IPCC 2014a; Chen et al. 2021). In Asian economies, the deployment of low-carbon technologies, along with accelerating the investment in emerging and new technologies, is required to transform the energy sources in these countries towards being renewable and clean (Brooks and Holstein 2019). In this regard, various Asian countries are currently emphasizing renewable energy generation goals through financing, providing subsidies, and incentivizing renewable energy development projects (Byun 2013). A reflection of this scenario can be visualized in the coefficient of energy innovation, which exerts a significant negative effect on GHG emissions. In the short run, a 1% increase in energy innovation is associated with a 0.67% reduction in GHG emissions, and more than a 1% decrease in the long run. This particular segment of the outcomes is along similar lines to the report developed by USAID (2011), which mentions that between 1990 and 2008, several Asian regions and countries made some progress in reducing GHG emissions by means of achieving energy efficiency (USAID 2011). Therefore, emphasizing energy innovation can reduce GHG emissions substantially in Asian countries.

Now, with energy innovation, policy interventions are also required to reduce GHG emissions, as innovation is enabled by regulatory environments (Mohideen 2018). Following this argument, the coefficient of PCI shows that a 1% increase in the political constraint in the Asian economies will increase the GHG emissions by 0.10% in the short run and by 0.06% in the long run. A higher capital risk and risk-aversion characteristics of the investors have characteristically resulted in low investment in clean energy projects, and the prevailing pro-growth policy agenda of the policymakers is worsening the environmental quality in these nations. Therefore, in order to reduce these risks, governments need to play a significant role by subsidizing research and development by private entities, promoting and implementing carbon regulation, and ensuring funding opportunities for universities and large-scale projects with the intention of making the transition path towards clean energy smoother (Jordaan et al. 2017). This segment of the results is similar to the findings of Khan and Rana (2021). These findings, however, contrast with the results of Sabir, Qayyum, and Majeed (2020), who found that law and order did not have a significant effect on environmental degradation, either in the short run or in the long run.

Following this, the impact of regional integration on GHG emissions will be discussed. The study outcome shows that the coefficient of regional integration indicates a positive effect on greenhouse gas emissions both in the short run and long run, implying that more integration between Asian economies increases the GHG emissions. Because of the continued dependence on fossil fuel-based solutions, Asian countries are encountering the problem of energy poverty, and therefore the technology transfer in these economies is mostly obsolete and traditional, relying on fossil fuel sources. This region also possesses a quarter of the global coal reserves, and therefore, regional integration in the energy sector among the Asian countries is most likely to be in the form of traditional energy sources. A report by ADB highlights that, if Asian countries cannot change the energy mix and continue to rely on fossil fuel sources for energy consumption, carbon dioxide emissions in these countries will double to approximately 24 billion tons every year to 2035, posing a grave threat to the Asian environment and human health (Lee, Park, and Saunders 2014). Dependence on fossil fuel energy is gradually leading to potential regional conflict and energy insecurity issues in these countries, which might have a negative impact on the environmental quality. Moreover, this region also lacks an effective regional network that can promote and share continuous improvement in clean energy regulations and policy (USAID 2011). This finding extends the claim by Alam et al. (2019), who stated that the regional trade integration among the South Asian nations can foster cross-border trade of fossil fuel energy resources rather than renewable energy, and this will further exacerbate the GHG emissions. This result is also consistent with the finding of Yu, Kim, and Cho (2011), who found that NAFTA has contributed towards the GHG emissions in both the US and Mexico. The authors argued that trade agreements between developing and developed countries often result in reallocating more polluting industries from developed countries to developing ones, due to the incompatible environmental regulations. Nemati, Hu, and Reed (2019) also mentioned that trade agreements between developing and developed countries worsen environmental quality by increasing greenhouse gas emissions. Moreover, Baghdadi, Martinez-Zarzoso, and Zitouna (2013) found that only regional trade agreements that incorporate environmental provisions affect the emissions level of a country. This lends support to our findings since most of the free trade agreements among the Asian countries have focused on deepening market-driven economic integration via FDI and trade, not on environmental provisions (Kawai and Wignaraja 2011).

Along with these issues, there are several challenges associated with climate change, such as the temporally and spatially heterogeneous and uncertain climatic impacts, the uneven distribution of emission sources, and varying mitigation costs. Yet, international cooperation carries the potential to tackle these problems simultaneously (Stavins et al. 2014). This is reflected in our finding that international cooperation, denoted by taxes on trade and international transactions, implies a significant negative effect on GHG emissions. Specifically, the estimation result demonstrates that a 1% increase in international cooperation will reduce GHG emissions by 0.28% in the short run and by 0.33% in the long run. This segment of the results resonates with the finding of Shahbaz et al. (2017) for the PRC and Zaidi et al. (2019) for Asia and the Pacific. Moreover, according to the IPCC, climate change is a global common problem, which can be handled by international cooperation through promoting and stimulating financial incentives and public investment (Stavins et al. 2014).

While stating the possible policy interventions, it is necessary to remember that these interventions might not reach their full potential because of the structural imbalance of the economy, which might stem from the incidents of social inequality. The coefficient of social inequality suggests that it has a positive and significant impact on GHG emissions both in the short run and in the long run. The underlying theory behind this finding can be referred to as the *political economy approach* introduced by Boyce (1994) and later developed by Downey (2015). This framework suggests that when wealth is more unequally distributed, it leads to greater environmental damage. Furthermore, when the rich portion of the society achieves political leverage by utilizing their wealth power, it results in poor environmental regulation and standards, which further intensifies the negative effect of inequality on carbon emissions (Guo, You, and Lee 2020). This segment of the results corroborates the findings of Knight, Schor, and Jorgenson (2017), who found that wealth inequality, measured by concentration of wealth in the top decile, has a stable positive impact on consumption-based carbon emissions in high-income countries.

4.2 Discussion of Interactive Impacts

While the model parameters will have certain individual impacts on GHG emissions, within a given unified policy framework, they interact with each other, and therefore the impact of energy innovation on GHG emissions will encounter a moderating effect of the other policy instruments. Following Eqs. (3) and (4), Models 2 and 3 have captured these moderating effects by means of interactions. This section discusses these interactive effects.

While looking at the interactive effect of the political constraint index in Model 2, the results reveal that political constraint reduces the effect of energy innovation on GHG emissions, suggesting that policy-level stringency diminishes the potential of investment in energy efficiency or innovation to reduce GHG emissions. As the government plays a crucial role in advancing innovation, tackling the GHG emissions through enhancing energy innovation will require policy realignment (Lee, Park, and Saunders 2014). Thus, environmental policies in Asian economies need to be adaptive so that the political constraints can be reduced, and the country's ability to enact GHG mitigation policies can be improved by reducing their vulnerability to climate change (Jenkins and Karplus 2016). This segment of the results also indicates the need for sustained reforms of policy and governance in the energy sector to materialize the energy innovation investments (USAID 2011). Discussion on political intervention needs to be complemented by an impact assessment of regional integration and international cooperation. The interactive effect of regional integration in Model 2

suggests a positive impact on GHG emissions in these economies. However, this effect is only significant in the short run, while the effect turns out to be insignificant in the long run. This indicates that in the short run, the environmental impact of energy innovation is offset by outdated technology transfer via the regional integration route. Nevertheless, in the long run, the diffusion of energy innovation might weaken this effect. On the other hand, the interactive effect of international cooperation enhances the environmental impact of energy innovation. Stabilizing climatic conditions through the reduction of GHG emissions necessitates cooperation among different nations (Paroussos et al. 2019). It is evident from the study outcomes that while international cooperation reduces GHG emissions by 0.28% and 0.33% in the short and long run, its interactive effect on the environmental impact of energy innovation results in a reduction of GHG emissions by 0.30% and 1.22% in the short and long run, respectively. However, exploring the political and economic dimensions of the interactive effects might remain incomplete without analyzing the interactive effects exerted by the social dimension, and this aspect is fulfilled by the interactive effect of social inequality. The interactive effect of social inequality has a positive and significant effect on GHG emissions in both the short and the long run. This segment of the study outcomes suggests that in the presence of social inequality, the environmental impact of energy innovation diminishes. This finding is along similar lines to the finding of Bai et al. (2020), who showed that income inequality in the PRC can hinder the progress of renewable energy innovation and even increase the level of emissions.

Out of these four interactive effects, the effect of social imbalance might be considered the most critical, as this effect can bring forth a complete imbalance in the policy regime, and hence can result in the nonfulfillment of the policy objectives. This interactive effect of social inequality is captured in Model 3. The impact of interaction between energy innovation, regional integration, and social inequality on GHG emissions is significant and positive. On the other hand, the impact of interaction between energy innovation, international cooperation, and social inequality on GHG emissions is significant and negative. To put things into perspective, the coefficients of these two interactive effects are compared with the coefficients of the energy innovation-regional integration and energy innovation-international cooperation interactions, respectively, and the negative environmental impact is seen to be increased for both cases. This segment of the findings shows that the prevalence of social inequality in the economy can weaken and worsen the policy directions towards a clean energy transition, and a possible reason behind this situation might be that the disproportionate social imbalance created out of disproportionate accumulation of wealth might limit the access to the benefits of innovation, which in turn can increase the social divide. In such a scenario, policymakers might find it difficult to reach the grassroots level owing to the incidence of social inequality, and therefore the intended positive environmental externality to be exerted by energy innovation might not be achieved.

4.3 Discussion of Elasticity

In continuing with the discussion on individual and interactive effects of the model parameters, it is necessary to understand how the impact of energy innovation changes, given the moderating impact of the other external factors. In this pursuit, the elasticity of GHG emissions with respect to energy innovation is computed along the sample means of the model parameters, and the outcomes are reported in Table 6. In Model 1, the elasticity value of energy innovation is -1.4867 , and this impact of energy innovation is desirable. Now, this elasticity value is compared with the cross-elasticity values computed from Model 2, and the cross-elasticity values show that the

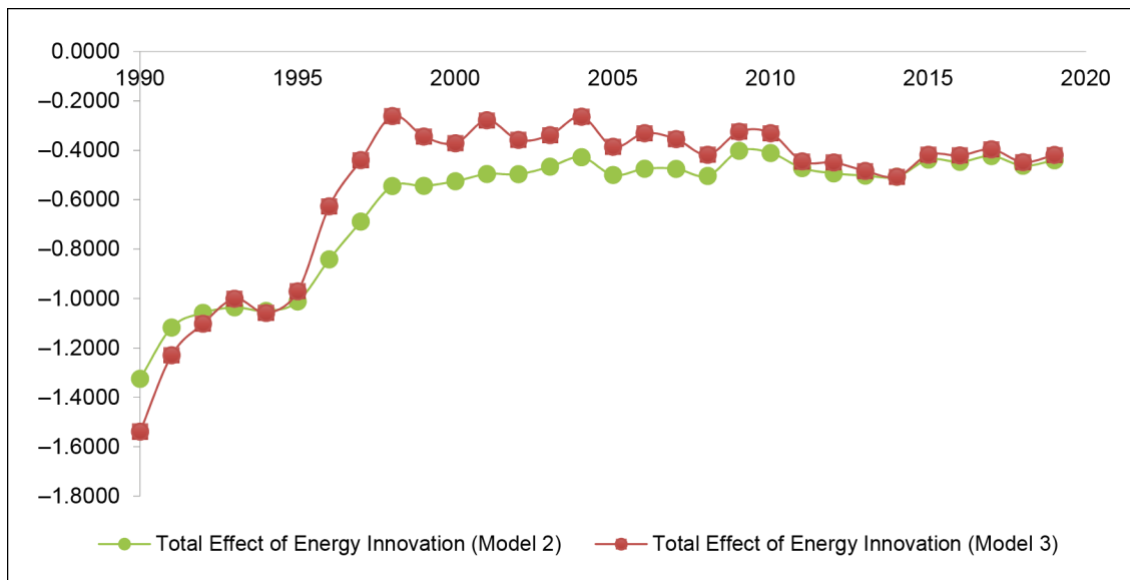
environmental impact of energy is increased in the presence of international cooperation, and it is reduced in the presence of regional integration, political constraint, and social inequality. This gives an indication that the more volume of trade there is within the Asian continent, stringency of policies and the prevalence of a consumption-driven social divide can hinder the progression of energy innovation, whereas improved trade relations with other countries from other continents creates a possibility of energy innovation reaching its full potential. However, in the present scenario, the coexistence of these factors reduces the overall impact of energy innovation in the Asian countries, and this is reflected in the overall cross-elasticity value (= -0.6872) of energy innovation. Now, the predominance of social inequality in the Asian countries has worsened the situation, as the overall cross-elasticity value (= -0.5172) of energy innovation in Model 3 is lower than that of the cases of Models 1 and 2. When compared to Model 2, the incidence of social inequality has further dampened the effect of international cooperation. Surprisingly, despite having demonstrated a dampening effect on energy innovation, the effect of social inequality is reduced in the case of the interaction with regional integration. This gives an indication that while these countries are treading along the growth path through international cooperation and regional integration, the latter might provide a solution to handle the problem of social inequality. As international cooperation will be required for the transfer of cleaner technologies, the regional integration channel might be utilized to develop the domestic capabilities of innovation, and this might help the Asian countries to allow cross-border movement of skilled and unskilled laborers. A progression along this direction might in turn improve the income level of the marginalized laborers and the social divide might be reduced.

Table 6: Changes in Cross-Elasticity of GHG Emissions with Respect to Energy Innovation

	Model 1	Model 2	Model 3
Total Effect	-1.4867	-0.6872	-0.5172
<i>Effect of Interactions</i>			
Interacting with REGINT	-	-0.3384	-0.2519
Interacting with INTCOP	-	-1.7272	-1.7490
Interacting with PCI	-	-1.1510	-0.9754
Interacting with SING	-	-0.8615	-0.6208
Interacting with REGINT and SING	-	-	-0.2231
Interacting with INTCOP and SING	-	-	-1.1060

In order to demonstrate the total effect of energy innovation on GHG emissions, its trend is shown in Figure 1. The trend shows that in the presence of exogenous moderation, the total effect of energy innovation is diminishing over time. This diminishing effect corroborates the discussion on elasticities reported in Table 1. This declining trend might be explained in terms of the scale effects exerted by the regional integration, political constraint, and social inequality.

Figure 1: Trend of the Total Effect of Energy Innovation on GHG Emissions for Two Models



4.4 Robustness Check Estimates

In order to assess the robustness of the CS-ARDL estimates, a cross-sectionally augmented distributed lag (CS-DL) procedure and cross-correlation estimates (CCE) are used. Based on the outcomes of long-run coefficient estimation using these two methods reported in Table 7, it is evident that the model parameters exhibit stability in terms of coefficient values, although the significance levels have changed to some extent. This segment of the outcomes has warranted robustness of the model estimates.

Table 7: Robustness Check Outcomes for Long-run Estimates

Model Parameters	CS-DL			CCE		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
EI	-1.3058 ^a	-0.7823a	-0.6848b	-1.1375a	-0.8508b	-0.5821
REGINT	0.1167 ^c	0.1587	0.1219b	0.1344	0.1428a	0.1515
INTCOP	-0.5908	-0.6156c	-0.8566	-0.9883c	-1.0159	-1.1242a
PCI	0.1360	0.2236	0.1390a	0.1653	0.1607	0.1004b
SINQ	0.0985 ^b	0.0587	0.0078	0.0640	0.0731c	0.0619
EI * REGINT	-	0.1885c	-0.0825	-	0.1732	-0.1076
EI * INTCOP	-	-1.4110a	-1.0084	-	-1.6870a	-1.2119a
EI * PCI	-	0.1752	0.7436	-	0.1425	0.8165a
EI * SINQ	-	0.2278	0.3784a	-	0.2851	-0.4016
EI * REGINT * SINQ	-	-	0.7956c	-	-	0.7608b
EI * INTCOP * SINQ	-	-	-0.8566	-	-	-0.9446

Note:

^a p-value < 0.01.

^b 0.01 < p-value < 0.05.

^c 0.05 < p-value < 0.10.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

This paper analyzes the impact of energy innovation on GHG emissions for the Asian countries over the period 1990–2019, and also assesses the moderating effects of social, political, and trade dimensions on this association by means of interactive impacts. Using the second-generation methodological approach, this study shows the changes in the impact of energy innovation under the influence of several internal and external factors. Based on insights received from the study outcomes, a policy framework will be designed.

5.1 Core Policy Framework

Following the analysis, the target policy framework should internalize the negative environmental externalities exerted by social inequality, regional integration, and political stringency, while enhancing the positive environmental externality exerted by international cooperation. Both of these aspects are necessary to realize the full benefits of energy innovation in reducing GHG emissions. Therefore, a phase-wise policy schedule needs to be designed, so that the policy instruments can be prioritized and worked upon in the respective phases. As social inequality has the highest moderating impact on the association between energy innovation and GHG emissions, the first phase needs to take account of this aspect. As social inequality arises out of consumption inequality, the policy moves should be directed in such a way that all citizens can have access to the essentials, and in order to achieve this, a steady income generation process is required. The regional integration route might be utilized to create job opportunities, and this process might entail cross-border movement of skilled and unskilled laborers. As the economic growth patterns of Asian countries differ, movement of laborers should be allowed towards those countries with higher growth potential. As long as comparatively economically backward countries improve the domestic capability to innovate, this cross-border movement of laborers in the traditional economic sectors might help in improving the level of per capita income. This particular policy move should be short-term in nature, as the regional integration in the traditional sectors adds to the GHG emissions, but a rise in the household income level might serve as a short-term solution in handling the social inequality issue. Moreover, a reduction in the social inequality and an improvement in household income level might help in diffusing energy innovation solutions within a nation, as a rise in income might lead improved accessibility of those solutions.

In order to have a long-term solution to this problem, an international cooperation route needs to be utilized in the second phase. As the regional integration might help in boosting the traditional sectors to grow and maintain the economic growth trajectory, international cooperation might help in developing those sectors towards being cleaner and sustainable. However, overnight transformation in the energy utilization pattern or existing production processes might hamper both the economic growth and social balance. Therefore, the intervention of financial intermediation might be necessary in this regard. The policymakers need to utilize the financialization channels to boost the diffusion and adoption of cleaner technologies achieved via international trade. At the same time, firms should be instructed to bring changes in their production processes within a stipulated time, and the respective governments might make these solutions available against a pro rata rate. Now, to avail themselves of these solutions, the firms might need loans and advances from the financial institutions. During this period, the financial institutions might need to introduce a discriminatory interest rate mechanism based on the ecological footprint of the firms, i.e., the dirtier firms will have to bear a higher rate of interest in availing themselves of those solutions, whereas the

comparatively cleaner firms will have to pay a lower rate of interest. While this mechanism is operational, the financial institutions need to ensure that the higher interest rate bracket should not discourage the dirtier firms from adopting the solutions or going out of business. This should push the firms to adopt cleaner technologies in a hassle-free manner. The interest income received via this channel should be utilized to subsidize the solutions for household usage. In this way, the demand for energy innovation can be created within the economy.

As this phase is operational, the investment climate for the energy innovation projects will also start to improve, and in order to achieve economies of scale, international investment will also be necessary. Therefore, in the third phase of the policy framework, political stringency and constraints should be relaxed, so that the countries can attract international investments, and the associated political risk of investment is reduced. Given that the domestic demand for energy innovation is rising and boosting the development of innovation capabilities might require additional investment, the political risk of investment will gradually go down. Therefore, relaxing the political constraints will lead to further development and diffusion of energy innovation technologies, thereby helping the first two phases to stabilize and sustain.

While all these three phases are operational, the countries will experience a rise in the number of energy innovation projects, and this will help these nations with fulfillment of the energy demand and achievement of energy security. With the fulfillment of these goals, these nations will be able to progress towards accomplishing the SDG 7 objectives. Simultaneously, growing adoption and dissemination of these solutions will consequentially help in mitigating the issue of rising GHG emissions in these nations. This accomplishment will push these nations to accomplish the objectives of SDG 13.

5.2 Tangential Policy Framework

While the core policy framework is operational and derived directly from the study outcomes, the tangential policy framework might be derived by extrapolating the study outcomes in such a way that the core policy framework can be supported. As these countries will be treading along the path to domestically develop energy innovation solutions, the policymakers need to make the citizens aware of the environmental benefits of these solutions, while focusing on the climatic issues caused by the unsustainable usage of fossil fuel-based solutions. In order to institutionalize this environmental awareness, the policymakers need to make certain amendments to educational curriculums. This will make students aware not only of the latest developments in the field of energy innovation, but also of the growing environmental concern around the world. This initiative will help sustain the demand for energy innovation and cleaner energy, and the innovation climate of these countries will also improve. Moreover, this initiative will also help these countries to progress towards achieving the objectives of SDG 9. This tangential policy framework represents the fourth phase of the entire policy framework, and it might help sustain the first three phases of the policy framework.

5.3 Assumptions of Framework

Discussion of policy framework might remain incomplete without discussing the assumptions that might enable the policy to reach its full potential. First, before finalizing the discriminatory interest rate brackets, firms' willingness to pay should be assessed, as the higher rate of interest will discourage firms from adopting the solutions. Second, the bureaucratic mechanism should be free from rent-seeking

mechanisms, as it may deter the diffusion of the energy innovation solutions. Third, rehabilitation of the laborers working in the existing fossil fuel-based power generation sector should be taken care of by the policymakers, as unemployment in this sector might raise the social inequality and might create a deterrence in the implementation of the policy framework.

5.4 Limitations and Future Directions

The policy framework recommended in the study has considered 23 Asian countries, and hence the inclusiveness of the policy framework can be questioned. However, the issues addressed in the study are nearly present for all Asian countries, and therefore this policy framework bears a level of generalizability, which makes it a benchmark policy framework baseline for the remaining Asian countries. Moreover, considering the spatial dimension of the emissions and bilateral trade could have spawned further insights in the study. Nevertheless, it is worth mentioning that the policy framework is flexible enough to accommodate additional policy instruments, those that are contextually relevant, and that creates a future direction for research in this pursuit.

APPENDIX 1: LIST OF COUNTRIES INCLUDED IN THE STUDY

Armenia	Kazakhstan	Philippines
Azerbaijan	Korea, Rep.	Singapore
Bangladesh	Kyrgyz Republic	Sri Lanka
Cambodia	Lao PDR	Tajikistan
PRC	Malaysia	Thailand
India	Mongolia	Uzbekistan
Indonesia	Nepal	Viet Nam
Japan	Pakistan	

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