# Foreign Direct Investment, Trade Openness and Solar Energy Capacity Addition: Evidence from China using QARDL

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**Abstract**

The world is facing the consequences of human-induced climate change calling for an aggressive shift towards renewable energy. The paper explores the effect of select macroeconomic variables on solar energy generation capacity, which is one of the most important components of the current energy mix. Quantile Auto-Regressive Distributed Lag approach is used in the context of China to explore the effect of gross domestic product (GDP), foreign direct investment (FDI), both inflows and outflows, and trade openness (TO) on solar energy generation. The period of analysis spans from 2002 to 2023, which represents the most recent available data. Earlier periods were rightfully excluded, as the dynamics of solar energy capacity addition were markedly different from the present. The study finds that there is a significant positive relationship between GDP and solar energy capacity addition as expected. More importantly, the study reveals the positive effect of FDI inflows but negative effect of TO on solar energy. Further, it is found that the FDI outflow partly affects the solar energy generation capacity addition. The article advocates for a policy push to optimally manage the FDI and international trade for combating climate change, in line with Sustainable Development Goals, through greener energy production.

Keywords: solar energy, quantile auto-regressive distributed lag, foreign direct investment, trade openness, sustainable development goals (SDGs), China

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## 1. Introduction

The world is grappling with climate change, evident from harsh heatwaves and extreme precipitation events in 2023, leading to flash floods, fatalities, and economic losses [1,2]. Scientists largely agree that unsustainable fossil fuel-based energy production, a major source of carbon dioxide emissions, is the primary culprit. These greenhouse gases drive global warming, triggering extreme weather events. Transitioning to sustainable energy is critical for development and mitigating the environmental damage caused by conventional energy practices [3].

Fortunately, the world has started to invest substantially in the renewable energy front. Renewable electricity capacity additions reached an estimated 507 GW in 2023, almost 50% higher than in 2022 [4]. Large scale deployment in China, among other countries, in different renewable technologies is being observed. Renewable energy is not only good for the environment but also has a multitude of other benefits. The extensive deployment of solar and wind energy has been observed to provide the added benefit of increased income for residents in various regions worldwide, with China being a notable example [5,6]. Many governments are taking steps to enhance renewable energy capacity; for example, China's "3060 Goal" includes a 65% reduction in carbon intensity from 2005 levels and a 25% share of non-fossil fuels by 2030, with over 80% non-fossil energy consumption by 2060 [7]. It is now a stylized fact that governments must implement an energy policy that strives to provide people with energy security at affordable prices while also being environmentally sustainable [8].

An important observation is that renewable energy sources compete for scarce resources and government policy support. Notably, solar energy is poised to become the flagship technology in the future sustainable energy mix, as the existing literature has highlighted the superiority of solar sources over wind energy [9].

The tremendous growth potential in renewable energy capacity and the complex and rapidly changing dynamics of the global energy system call for continuous scholarly scrutiny of the subject matter. Against this backdrop, the article attempts to evaluate the role of macroeconomic variables of FDI and trade openness in the growth of solar energy proliferation in China.

The intricate relationship between FDI, renewable energy development, and carbon emissions has garnered significant attention in recent years as countries strive to balance economic growth with environmental sustainability. As a novelty, this study explores the impact of FDI inflows and outflows on solar energy development. While much of the existing literature has focused on the effects of FDI inflows on host countries, the role of FDI outflows from home countries in shaping renewable energy landscapes globally has received comparatively less attention. This paper argues that a comprehensive understanding of the FDI-renewable energy nexus requires consideration of both dimensions. Furthermore, the impact of FDI on renewable energy exhibits asymmetry, as its effects vary across countries at different stages of economic development. Emerging economies, for instance, may benefit more from FDI inflows in terms of renewable energy adoption compared to the developed countries with already established clean energy sectors. Similarly, the impact of FDI outflows on renewable energy may vary depending on the technological capabilities and energy policies of the home country [10].

The complex relationship between FDI, economic development, carbon emissions, and renewable energy is further influenced by global efforts to combat climate change. International agreements such as the Paris Agreement have created a framework for countries to reduce their carbon emissions, enabling a transition to cleaner energy sources. These global commitments have the potential to reshape FDI flows, directing more investment towards renewable energy projects and low-carbon technologies [11].

As countries strive to meet their climate goals, the role of FDI in facilitating the transition to renewable energy becomes increasingly important. However, the effectiveness of FDI in promoting renewable energy adoption may depend on various factors, including the quality of institutions, the stringency of environmental regulations, and the level of technological readiness in both home and host countries [12]. The potential positive impacts of FDI on renewable energy development include technology transfer, capital injection, and management expertise. However, these benefits may not be realized uniformly across all countries or types of FDI. Inward FDI might be particularly crucial for developing countries lacking the necessary technology or capital, while outward FDI from developed countries could play a significant role in disseminating renewable energy technologies globally. The relationship between FDI and renewable energy development is complex and multifaceted. The impact of FDI inflows and outflows on renewable energy highlights the importance of considering country-specific factors such as technological capabilities, policy environments, market characteristics, and economic structures.

Policy environments shape the attractiveness and effectiveness of renewable energy investments [13]. Market size can potentially influence overall FDI in the energy sector, with varying distributions between renewable and non-renewable investments [14]. A country's economic structure, including its energy mix and industrial composition, can either facilitate or hinder renewable energy transition [15]. In addition, a country's position in global value chains determines whether it benefits to a larger extent from inward or outward FDI in the renewable sector [16].

The chain of relationships from energy consumption to economic development, to carbon emissions, to renewable energy adoption, and finally to FDI flows, demonstrates the interconnected nature of these economic and environmental factors. This complexity necessitates a nuanced approach to both research and policy-making in this area. The article partly traces the complex chain of relationships from energy consumption to economic development, carbon emissions, renewable energy adoption, and ultimately, FDI flows and trade openness. The rest of the article is organized as follows: relevant literature is reviewed in section 2 which is followed by the discussion on data and methodology in section 3. The results are discussed in section 4, and the article is concluded in section 5.

## 2. Theoretical Underpinnings and Literature Review

Energy has long been recognized as a crucial driver of economic development. As economies grow, their energy demands increase, fueling further expansion and industrialization [17]. However, this growth-energy nexus has traditionally relied heavily on fossil fuels, leading to a parallel increase in carbon emissions. The resulting environmental degradation and global climate change concerns have prompted a shift towards more sustainable energy sources, particularly renewable energy [18]. One prominent theoretical framework that forms the basis of this study is the Environmental Kuznets Curve (EKC) [19]. EKC implies that pollution levels tend to intensify with the rise in the level of economic growth, and it subsequently reduces after crossing a certain threshold [20]. This phenomenon can be attributed to the aggressive consumption and exploitation of resources in the initial stages to achieve economic growth without considering its adverse impact on the environment. Economies tend to prioritize environmental sustainability only after achieving economic growth. With the help of technological innovation and eco-friendly initiatives, economies tend to reduce the adverse impact on the environment to ensure sustainable growth. China is now moving toward the correction phase in the EKC, where it aggressively needs to invest in initiatives to improve environmental quality. One major initiative in this regard focuses on the global system of capacity building in the energy sector. Under the aegis of sustainable development goals, the global energy sector requires significant investment in renewable energy, especially solar energy.

With reference to the FDI and trade openness, another relevant theory is the Market Imperfection Theory [21]. This theory suggests that investment in foreign markets allows firms to capitalize on capabilities that the host country has yet to fully develop [22]. FDI, both inward and outward, plays a multifaceted role in this energy-development-emissions-renewables nexus. FDI inflows can bring much-needed capital, technology transfer, and management expertise to host countries, potentially accelerating their transition to renewable energy [23]. Conversely, FDI outflows from developed economies may represent a transfer of renewable energy technologies and best practices to emerging markets, contributing to global efforts in combating climate change [24].

The transition to renewable energy is not merely an environmental imperative but also an economic opportunity. Countries investing in renewable energy technologies often see benefits in terms of energy security, job creation, and long-term economic sustainability [25]. This is true for solar energy also because the entire value chain of solar energy technology has economic implications including job opportunities. However, the development and deployment of renewable energy infrastructure require significant capital investment, technical expertise, and supportive policy frameworks. This is where the pivotal role of FDI becomes evident. FDI outflows can influence renewable energy development through various channels. Multinational corporations (MNCs) from countries with advanced renewable energy sectors may export their technologies and expertise to other markets, potentially accelerating the adoption of clean energy solutions in host countries. Conversely, outward FDI from countries heavily invested in fossil fuel industries may impede the transition to renewable energy in host countries by perpetuating carbon-intensive practices [26].

Various researchers have studied renewable energy around the themes of economic growth, FDI, and trade openness. Table 1 presents a thematic analysis around a few key findings that lay the theoretical foundation for this study.

**Table 1:** *Thematic analysis with reference to renewable energy*

| Themes | Findings | Authors (Year) |
|---|---|---|
| Economic Growth | Promoting renewable energy improves the economic conditions of the countries [27]. | Inglesi-Lotz (2016) |
| | There is a bi-directional causality between economic growth and renewable energy consumption in OECD countries [28]. | Apergis and Payne (2010) |
| | For the N-11 countries, renewable energy consumption boosts economic growth in the short run [29]. | Yang et al. (2022) |
| FDI | FDI is one significant tool that promotes energy-efficient technology. FDI inflows are a source of solar technology promotion [30]. | Yasmeen et al. (2022) |
| | In the long run, with the GDP growth slowing down, energy-focused FDI will boost the renewable energy capacity in China [31]. | Fan and Hao (2020) |
| | FDI accelerates the transformation to cleaner energy systems [32]. | Keeley and Matsumoto (2018) |
| Trade Openness | Trade openness significantly influences renewable energy use over the long term in OECD countries [33]. | Alam and Murad (2020) |
| | Trade openness delays carbon neutrality accomplishments in China [34]. | Ahmed et al. (2021) |
| | Trade openness negatively affects the renewable energy intensity in China [35]. | Wang et al. (2023) |

It is generally accepted that, in recent years, FDI has discouraged the use of conventional energy [36]. Existing research has identified a substantial long-term association between economic globalization through FDI, the consumption of renewable energy, and economic growth across certain countries [37]. Somewhat counterintuitively, [38] found that FDI is negatively correlated with the share of renewable energy, though the negative effect is relatively small, and it is most likely because of the time delay in technology diffusion. Along similar lines, [39] found that there is a significant and negative relationship between FDI and renewable energy in South Asian nations. On the contrary, [40] observed a positive relationship between renewable energy and FDI for a panel of 39 countries over the period from 2000 to 2019.

In the context of China, [41] notes that there is a unidirectional causality running from GDP and FDI to renewable energy consumption in the long run, but, in the short run, FDI may not significantly cause renewable energy consumption change. The results of the study conducted by [42] showed a bidirectional connection between renewable energy consumption and FDI in developed countries, whereas only a unidirectional link was observed from foreign inflows to energy consumption for both the forms of energy – renewable and conventional. [43] acknowledges that FDI promotes energy efficiency and green energy but data for Bangladesh, for the period 1980 to 2015, showed no such short-run linkages between FDI and renewable energy consumption, though long-run bidirectional causality was observed.

A study by [44] using a panel of 16 countries for the period 1990 to 2019 showed that FDI promotes the consumption of greener forms of energy through the advancement of investment activities in less developed countries of Asia that lack capital. Using a panel of developing countries from 1991 to 2021, [45] detects a significant negative relationship between economic growth and renewable energy consumption, as well as between FDI and renewable energy consumption, in the long run. Interestingly, this significance disappears in the short run. In the context of the United Arab Emirates, [46] observed significant empirical evidence that FDI and economic growth can significantly increase renewable energy consumption.

For the Central Asian countries of Kazakhstan and Uzbekistan, using data from 1992 to 2018, [47] found that there is a bidirectional linkage between FDI and renewable energy consumption. Using a panel of countries for the period 1980 to 2021, [48] found evidence for bidirectional causality between FDI and renewable energy consumption. For South Asian countries, [49] found that FDI negatively affects renewable energy consumption. Based on the discussion of extant literature, the environmental impact of FDI remains inconclusive, and environmental regulation may play a moderating role alongside other variables [50].

With respect to trade openness, using the data from select emerging countries for the period 1980 to 2015 [51] showed that the increase in the use of renewable energy is an important factor in decreasing trade openness. On the contrary, [52] found that an improvement in trade openness leads to renewable energy consumption. Based on the extant review of literature, the following research questions (RQs) have been formulated:

- **RQ1:** Does economic growth impact solar energy capacity addition?
- **RQ2:** Do FDI inflows and outflows impact solar energy capacity addition?
- **RQ3:** Does trade openness impact solar energy capacity addition?

There are multiple gaps in the literature on renewable energy and FDI nexus. Firstly, the results are ambiguous. This is possibly due to the omission of variables or failure to consider moderating variables. The heterogeneity in methodological approaches across studies indicates that the findings may lack consistent robustness and are likely dependent on the specific econometric models employed in the respective analyses. Secondly, the results depend on the geography considered, and the huge asymmetry calls for a set of studies independently focusing on different geographies.

Thirdly, the period of analysis is, in many cases, too old to be of relevance. Large-scale renewable energy was too costly prior to the turn of the 21st century, and except for hydropower and a relatively small amount of wind power, no other sources were deployed at a significant scale. Therefore, reliance on older data may not provide adequate and reliable insights. Fourthly, in a majority of the studies, the methodology adopted is variants of mean-based approaches.

Quantile-based regressions are scantly used to assess the relationship between FDI and renewable energy consumption.

Fifthly, the studies almost invariably consider renewable energy consumption as the variable of interest. Though renewable energy consumption is a relevant variable, the effect on renewable energy generation capacity is inadequately explored in the literature. Variables such as FDI and trade openness have a major effect on renewable energy generation capacity addition. The solar energy generation is contingent upon the adequate renewable energy infrastructure. The robust infrastructure is very much part of sustainable development and the same is highlighted in SDG 9 - building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation. Increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes (Target 9.4) are undoubtedly a positive consequence of FDI. Renewable energy generation depends on multiple other factors, such as insolation, wind speed, and other geographic variables, as well as the energy prices and intensity of demand, which are not otherwise fulfilled through conventional energy sources.

Sixthly, the effect of FDI on specifically solar energy is hardly evaluated in the literature. We must note that solar energy is the most promising form of renewable energy for the future, and there is a huge gap in the literature in assessing the effect of FDI on solar energy. Seventhly, the literature has not, in general, separately covered the effects of incoming and outgoing capital on renewable energy consumption. The present work attempts to fill some of the above-mentioned gaps in the extant literature. Figure 1 presents the conceptual model.

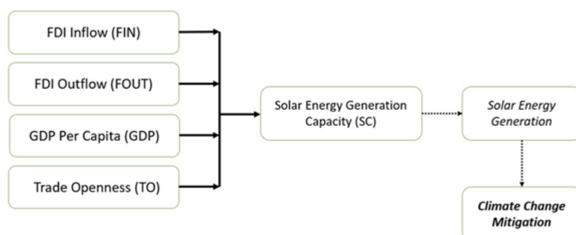


**Figure 1:** *Conceptual model*

The Quantile Autoregressive Distributed Lag (QARDL) models assess the impact of independent variables on the dependent variable using the median (or any other quantile). This is in contrast to the traditional least square approaches where the mean of the variable is at the core. QARDL has potential advantages from the policy perspective as noted by [53, 54]. Using QARDL, [55] has established, among other findings, that renewable energy consumption and economic growth are causally linked through a bidirectional relationship. QARDL is applied by [56], which provides analysis across different quantiles of the dependent variable, to estimate the relationship between the variables of oil prices, exchange rate, and stock market returns. [57] examined the short-run and long-run effects of exchange rate across quantiles of energy demand using QARDL. Using the QARDL, [58] studied the dynamic and causal relationship between green investment, clean energy, economic growth, and environmental sustainability. On similar lines, [59] established that renewable energy consumption negatively influences carbon emissions across all quantiles. [60] attempted to study the role of various factors on environmental sustainability from 2000 to 2020, using the QARDL, which is a resilient and sophisticated approach. The novel method of QARDL is used by [61] to portray the dependence patterns of the variables emphasizing the nexus of eco-innovation and ecological footprint for China. We observe that QARDL is a popular approach in the most recent literature in energy economics.

This study aligns with the United Nations Sustainable Development Goals (UNSDGs) by exploring its relevance to achieving affordable, reliable, sustainable, and modern energy access for all (Goal 7). Specifically, it investigates the impact of macroeconomic factors, including FDI, on the expansion of solar energy generation capacity, which is crucial for increasing the share of renewable energy in the global energy mix, mobilizing international financial flows to support renewable energy production, and expanding the installed capacity of renewable energy-based power plants (Goal 7 targets and indicators). Additionally, this research contributes to the objective of revitalizing the global partnership for sustainable development (Goal 17) by examining how financial resources, including FDI, can be effectively mobilized to support developing countries' renewable energy efforts (Target 17.3).

## 3. Data and Methodology

The data for the purpose of analysis is obtained from a couple of sources. The macroeconomic data is obtained from the World Development Indicators (WDI) of the World Bank, and the solar energy capacity data is the proprietary data of the International Energy Agency (IEA). The analysis period spans from 2002 to 2023. We have used the most recent available dataset. The rationale for excluding the years prior to 2002 is the fact that the solar energy generation capacity was hardly significant before the selected period, and this is evident from the data source. The table below (Table 2) describes the data. We have taken the last five-year average as the imputation, which is reasonable enough. The descriptive statistics are presented in Table 3. The variables are taken in natural logarithmic form for the purpose of analysis.

**Table 2:** *Variables description*

| Variable | Description | Unit |
|---|---|---|
| SC | The Solar Energy Generation Capacity | GW |
| GDP | Gross Domestic Product Per Capita (in Purchasing Power Parity Terms) | 2021 International Dollars |
| TO | Trade Openness (Ratio of Export plus Import to GDP) | Ratio |
| FIN | Foreign Direct Investment Inflow | Billion Dollar |
| FOUT | Foreign Direct Investment Outflow | Billion Dollar |

Note: All the variables are taken in natural logarithms for the purpose of analysis

**Table 3:** *Descriptive statistics of the variables*

| Variable | Min | Max | Mean | Median | Std Dev | Skewness | Kurtosis | JB Test |
|---|---|---|---|---|---|---|---|---|
| SC (GW) | 0.04 | 645.11 | 107.08 | 11.98 | 168.52 | 1.81 | 3.62 | 18.145*** |
| GDP (Int $) | 4290.30 | 21019.46 | 11869.13 | 11586.24 | 5286.84 | 0.17 | -1.26 | 1.545 |
| TO (%) | 34.75 | 64.48 | 46.52 | 45.05 | 9.44 | 0.54 | -1.00 | 2.061 |
| FIN (Bn $) | 115.05 | 331.32 | 232.24 | 248.55 | 64.76 | -0.174 | -1.057 | 1.205 |
| FOUT (Bn $) | 15.4 | 243.53 | 95.3 | 78.79 | 63.46 | 0.486 | -0.614 | 1.373 |

The Quantile Autoregressive Distributed Lag (QARDL) process due to [62] can be represented by the following equation:

$$\begin{aligned} SC_t = &\alpha_*(\tau) + \sum_{j=1}^{p} \phi_{j*}(\tau) SC_{t-j} + \sum_{j=0}^{q_1} \theta_{1j*}(\tau) GDP_{t-j} \\ &+ \sum_{j=0}^{q_2} \theta_{2j*}(\tau) FIN_{t-j} + \sum_{j=0}^{q_3} \theta_{3j*}(\tau) FOUT_{t-j} + \sum_{j=0}^{q_4} \theta_{4j*}(\tau) TO_{t-j} + U_t(\tau) \end{aligned} \tag{1}$$

For the purpose of analysing QARDL, the above equation is reformulated as follows:

$$
\begin{aligned}
SC_t =&\alpha_*(\tau) + \sum_{j=1}^{p} \phi_{j*}(\tau) SC_{t-j} + \sum_{j=0}^{q_1-1} \delta_{1j*}(\tau)\Delta GDP_{t-j} + \sum_{j=0}^{q_2-1} \delta_{2j*}(\tau)\Delta FIN_{t-j} \\
&+ \sum_{j=0}^{q_3-1} \delta_{3j*}(\tau)\Delta FOUT_{t-j} + \sum_{j=0}^{q_4-1} \delta_{4j*}(\tau)\Delta TO_{t-j} \\
&+ \gamma_{1*}(\tau)GDP_t + \gamma_{2*}(\tau)FIN_t + \gamma_{3*}(\tau)FOUT_t + \gamma_{4*}(\tau)TO_t + U_t(\tau)
\end{aligned} \tag{2}
$$

This essentially captures the short run dynamics. To capture the long run dynamics, the following formulation is used:

$$
SC_t = \mu_*(\tau) + \beta_{1*}(\tau)GDP_t + \beta_{2*}(\tau)FIN_t + \beta_{3*}(\tau)FOUT_t + \gamma_{4*}(\tau)TO_t + R_t(\tau) \tag{3}
$$

A QARDL-ECM (Quantile Autoregressive Distributed Lag – Error Correction Model) form for the equation (1) is also required, and it is represented by the following equation:

$$
\Delta SC_t = \alpha_*(\tau) + \zeta_*(\tau)(SC_{t-1} - \beta^*(\tau)' X_{t-1}) + \sum_{j=1}^{p-1} \phi_j^*(\tau)\Delta Y_{t-j} + \sum_{j=0}^{q-1} \theta_j^*(\tau)' \Delta X_{t-j} + U_t(\tau) \tag{4}
$$

It may be noted that $\beta^*$ and $\theta^*$ are vectors of parameters. Similarly, $X$ and $\Delta X$ are the vectors of the regressors. Further, different regressors in the first difference form could be lagged differently for respective regressors. We have used these for notational simplicity only. Also, a standard notation is used, and hence, $\Delta X$ is nothing but just the set of regressors in the first difference form. The notation used is fully consistent with [62].

In the above formulations, $U_t$ and $R_t$ are error terms and $\tau$ specifies the quantile taken for the respective quantile regression, and hence, the median corresponds to $\tau = 0.5$.

## 4. Results and Discussion

The econometric analysis is done using EViews 14. First, we conduct unit root tests. It is necessary that the variables are, at most, integrated of the order one. We conduct two tests for unit root (stationarity): Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) [63,64]. Whereas the Null Hypothesis of ADF is that the series has a unit root, the Null Hypothesis of KPSS is that the series is stationary. Hence, for the ADF test, the Null Hypothesis must be rejected at the first difference level if it is not rejected at levels. On the other hand, for the KPSS test, the Null Hypothesis must not be rejected at the first difference levels. We find that the results are favorable in our case, and we may proceed with the analysis. The results are presented in Table 4. It may be noted from the results that for the Solar Capacity variable, the ADF test fails to show stationarity at the first B next (Table 5). The table shows all the relevant significant variables. The results are consistent, and to conserve space, we only report the results at the 50th percentile or the median ($\tau = 0.5$). However, we show the estimated values for multiple quantiles for our long-run cointegrating variables in Figure 2.

The lags of the dependent variable, Solar Capacity (SC), are all significant. The signs are positive for the first and the third lags, whereas the signs are negative for the second and the fourth lags. The significance shows that the auto-regression is a reasonable approach. The changing sign may be interpreted in the following way. A relatively large investment in solar energy is balanced in the year following, which is reasonable.

**Table 4:** *Unit root test results*

| Variable | ADF Level | First Diff. | KPSS Level | First Diff. |
|---|---|---|---|---|
| SC | -3.074 | -1.570 | 0.634** | 0.132 |
| GDP | 0.018 | -4.449*** | 0.177** | 0.106 |
| FIN | -2.736* | -3.769** | 0.417** | 0.253 |
| FOUT | -1.619 | -6.877*** | 0.596** | 0.118 |
| TO | -1.054 | -3.077** | 0.417* | 0.252 |

Null of ADF is Presence of Unit Root
Null of KPSS is Stationarity
***, ** and * denote significance at 1%, 5%, and 10% respectively

The significant and positive sign for Foreign Direct Investment Inflow (FIN) has a strong policy connotation. FDI Inflows are good for Solar Capacity addition and must be promoted. Foreign Direct Investment Outflow (FOUT) is also positive and significant; nevertheless, it has a much smaller coefficient. As expected, GDP has a positive and sizeable impact on Solar Capacity addition. The fast-growing economy of China in the past couple of decades has positively influenced Solar Capacity addition. As the variables are used in natural logarithmic form, the coefficient of 0.823 shows that a one percent growth in Gross Domestic Product (GDP) leads to almost similar (0.82%) growth in Solar Capacity addition.

Trade Openness (TO) has a negative impact on Solar Capacity addition. This is understandable as TO facilitates China's increased dependence on cheaper, imported fossil fuels. China's fast-paced economic growth has led to a growing reliance on imported fossil fuels, with oil dependency projected to reach around 70% by 2050 and gas dependency expected to range between 50% and 60% by 2030 [65]. Countries with open trade policies may prioritize energy imports over investing in renewable infrastructure, especially when fossil fuel prices are relatively low. This can create a "lock-in" effect where economies continue to depend on fossil fuels rather than transitioning to renewable energy sources like solar power. For example, it is emphasized in the literature how energy imports can stall renewable energy adoption when fossil fuels dominate the energy mix in open economies [66]. Further, the intercept term and the deterministic trend are both positive, which is also on the expected lines. It may be noted that the Akaike Information Criteria is used for model selection and we have used Epanechnikov Kernel for the estimation. The method used for bandwidth selection is Hal-Sheather and the bandwidth selected by the software was 0.37072. We have used the seed = 1 in the bootstrapping process for result reproducibility.

The basic requirement for the results to be dependable is the long-run cointegration among the variables. This is tested through the Bounds Test. The Null Hypothesis of No Levels Relationship must be rejected. Our model variables are clearly cointegrated as shown by the highly significant F-statistic (15073083***) and t-statistic (-1396.008***). Moreover, the cointegrating relationship is shown in Table 5.

Error Correction form of the QARDL has certain advantages, as it shows the short-run and long-run effects. A significant and negative error correction term is needed for model stability. The model is indeed stable as we do have a negative and highly significant error correction term in the error correction formulation (Table 6). All the relevant long-run and short-run coefficients are shown in the table. The signs are again consistent. Foreign Direct Investment Outflow (FOUT) has no short-run effect, and this is reasonable and consistent from an economic point of view.

As stated earlier, we present the estimated values for multiple quantiles for our long-run cointegrating variables in Figure 2. The estimates lie within the 95% confidence limit and there are differences in estimates before the median and after the median. Otherwise, the estimates are fairly constant. Dynamic Multiplier graphs for long-run cointegrating variables are shown in Figure 3. The graphs show that the variables converge to long-run limiting values.

**Table 5:** *QARDL Result (Dependent Variable: SC)*

| Estimated Quartile: Median | | | Long-Run Cointegrating Relationship (Deterministic Unrestricted trend) | | |
|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **t-Statistic** | **Variable** | **Coefficient** | **t-Statistic** |
| SC (-1) | 0.917 | 526.58*** | FIN (-1) | 3.056 | 1063.85*** |
| SC (-2) | -0.425 | -175.8*** | FOUT | 0.174 | 121.64*** |
| SC (-3) | 0.117 | 45.13** | GDP | 1.506 | 1307.24*** |
| SC (-4) | -0.156 | -92.81*** | TO (-1) | -6.993 | -1385.57*** |
| FIN | 0.148 | 128.16*** | | | |
| FIN (-1) | 0.448 | 369.96*** | | | |
| FIN (-2) | 0.402 | 309.23*** | | | |
| FIN (-3) | 0.138 | 94.91*** | | | |
| FIN (-4) | 0.534 | 345.33*** | | | |
| FOUT | 0.095 | 93.72*** | | | |
| GDP | 0.823 | 1309.8*** | | | |
| TO | -0.967 | -437.69*** | | | |
| TO (-1) | -1.65 | -639.9*** | | | |
| TO (-2) | 0.402 | 162.97*** | | | |
| TO (-3) | -1.606 | -591.99*** | | | |
| Constant | -2.326 | -350.02*** | | | |
| Trend | 0.085 | 227.84*** | | | |

Model selection based on AIC: (4,4,0,0,3)
Dependent Variable: SC (Solar Capacity)
*** and ** denote 1% and 5% significance respectively

The results are consistent, adhere to economic principles, and have interesting insights. The results lend themselves to strong policy implications for solar energy generation. The capacity addition is the pre-requisite for substantial solar power generation, and the strong role of Foreign Direct Investment Inflows is undeniable. The results are intense proof that Solar Capacity addition is highly contingent upon FDI Inflows. It is not only a lesson and policy prescription for China but also for other emerging economies such as India and possibly other BRICS nations.

**Table 6:** *Result of error correction model*

| | | |
|---|---|---|
| **Long-Run** | | |
| SC (-1) | -0.546 | -1396.01*** |
| FIN (-1) | 1.67 | 2117.2*** |
| FOUT | 0.095 | 122.46*** |
| GDP | 0.823 | 6784.64*** |
| TO (-1) | -3.821 | -4156.38*** |
| **Short-Run** | | |
| D.SC (-1) | 0.463 | 222.05*** |
| D.SC (-2) | 0.038 | 19.65** |
| D.SC (-3) | 0.156 | 80.31*** |
| | | |
| D.FIN | 0.148 | 88.72*** |
| D.FIN (-1) | -1.073 | -474.41*** |
| D.FIN (-2) | -0.671 | -353.55*** |
| D.FIN (-3) | -0.534 | -307.66*** |
| D.TO | -0.967 | -176.81*** |
| D.TO (-1) | 1.204 | 148.58*** |
| D.TO (-2) | 1.606 | 236*** |
| Constant | -2.326 | -721.42*** |
| Trend | 0.085 | 436.74*** |
| ECM | -0.546 | -1082.13*** |

Model selection based on AIC: (4,4,0,0,3)
Dependent variable: SC (Solar Capacity)
*** and ** denote 1% and 5% significance respectively

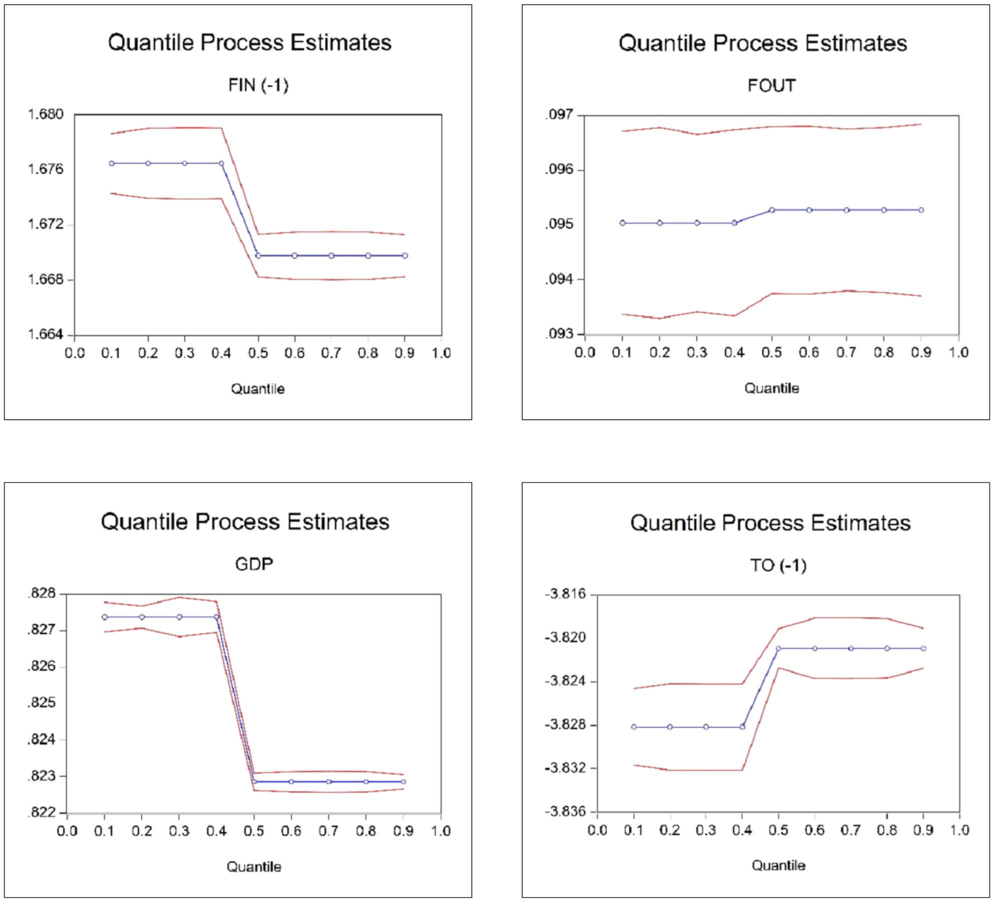


**Figure 2:** *Estimated values for long-run cointegrating variables at different quantiles*

## 5. Conclusion and Policy Implications

The article primarily discussed the role of FDI in promoting solar energy deployment, which is critical for the world that is facing the consequences of human-induced climate change. It is well accepted that a massive shift towards renewable sources of energy is the need of the hour. Solar energy is one of the most important renewable energy technologies for the future. The world is heavily investing in solar energy. This paper examined the impact of key macroeconomic factors, including GDP, FDI, and trade openness, on the growth of solar energy generation capacity. The article explores the case of China using a Quantile Auto-Regressive Distributed Lag approach. The study period of 2002 to 2023 is not only the most recent available but also the most important, as it was in the last two decades that solar energy gained relevance at a substantial scale. In contrast, the dynamics of solar energy capacity addition were vastly different in earlier periods when large-scale solar power was virtually non-existent.

Using the novel QARDL methodology, the analysis demonstrates a significant positive relationship between GDP and solar energy capacity addition. This finding underscores the link between a country's economic well-being and its ability to invest in renewable energy sources like solar. Higher GDP often translates to greater financial resources available for governments

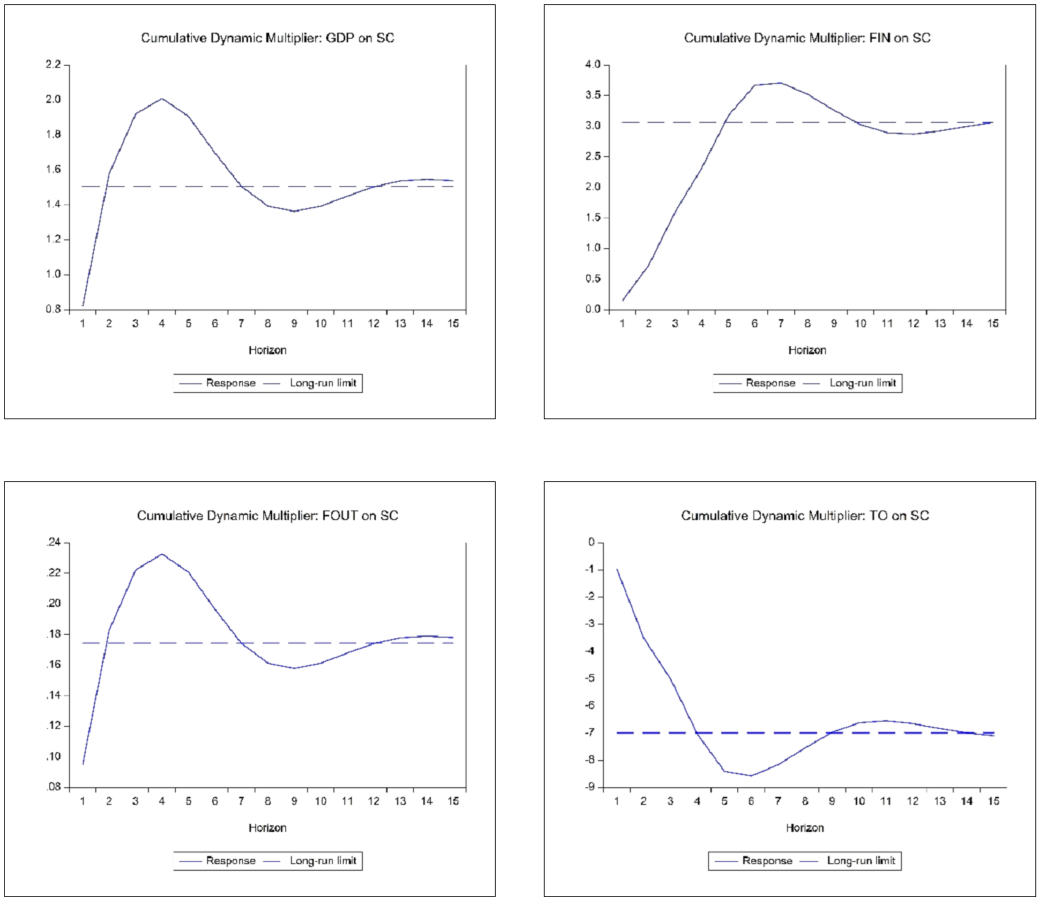


**Figure 3:** *Cumulative dynamic multiplier graphs (effect of independent variables on the dependent variable)*

and private companies to invest in solar energy projects [67]. This positive relationship can be used to emphasize the importance of policies that foster economic growth alongside sustainable development goals. When governments prioritize policies that promote both economic growth and renewable energy investments, it can create a positive feedback loop where higher GDP enables greater solar energy adoption, further boosting economic activity [68]. It has implications for the developing nations as well. As their economies grow, developing nations have a crucial opportunity to prioritize solar energy and leapfrog fossil fuel-dependent infrastructure. This can contribute to both their economic and environmental sustainability.

Crucially, the findings reveal that FDI inflows exert a favourable influence on solar energy deployment. This suggests that policies aimed at attracting FDI in the renewable energy sector can yield positive outcomes for solar energy deployment. FDI can bring in advanced technologies, managerial expertise, and access to global supply chains, all of which can accelerate solar energy adoption [69]. On the other hand, the study finds that increased trade openness may have an adverse impact on solar energy capacity addition. This is because increased trade openness leads to a more diverse energy mix, where cheaper fossil fuel-based energy sources compete with solar energy, potentially undermining the incentives for domestic solar energy investments [51].

Additionally, the study finds that outward FDI partly influences the expansion of solar energy generation capacity. This can be attributed to the fact that firms investing abroad tend to transfer technologies and know-how, which can indirectly benefit the solar energy sector in the home country [32]. However, the effect of outward FDI is weaker compared to inward FDI, as the primary objective of the outbound investment is to tap into new markets and resources rather than specifically promote renewable energy. The article advocates for a policy push to optimally manage FDI and international trade for combating climate change through greener energy production. Specifically, it suggests that policies aimed at attracting FDI in the renewable energy sector while maintaining a balanced approach to trade openness can be an effective strategy to drive solar energy capacity addition. Overall, the study provides useful insights for policymakers in developing countries seeking to promote solar energy adoption.

The work may be extended by incorporating asymmetric effects. The asymmetric nature of Foreign Direct Investment's impact on renewable energy in general and solar energy in particular becomes even more apparent when considering both inflows and outflows. Future research studies may explore the nuanced relationship between different types of FDI, like greenfield, mergers and acquisitions, and solar energy deployment, to further refine the policy implications. Additionally, future work may be focused on the dynamics of FDI in other renewable energy sources like wind, geothermal, and hydropower to gain a more comprehensive understanding of the role of FDI in renewable energy transition. Future research may investigate how environmental regulations and policies could potentially moderate the relationship between trade openness and solar energy capacity expansion, potentially resolving the apparent trade-off observed in the current study. Additionally, it may be worthwhile to investigate the specific channels through which trade liberalization affects domestic investments in solar energy, such as the interplay between imported fossil fuels, solar energy equipment, and local policy incentives. The results and their policy implication are in tune with the recommendations of [70] that the disbursement of climate finance, contingent on trade openness and foreign direct investment, and the role of international trade are to be studied thoroughly.

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