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RESEARCH ARTICLE

Exploring the potential of the belt and road initiative as a gateway for renewable energy in diverse economies

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Abstract
The Belt and Road Initiative (BRI), spearheaded by China, is anticipated to bolster trade, investment, and economic growth among participating countries to advance the United Nations' Sustainable Development Goal 7 through international trade. Within this context, renewable energy has emerged as a promising avenue to address environmental degradation and foster sustainable development. However, the impact of BRI's trade volume on renewable energy development and adoption in these nations remains unresolved. To address this, our study examines the influence of trade openness, foreign direct investment, economic growth, and oil prices on renewable energy consumption in 94 BRI countries with varying income levels from 2000 to 2019. Employing panel data analysis, including fixed effects (FE), random effects (RE), and the system generalised method of moments (GMM), we present findings across income groups: i) Trade openness exhibits a positive effect on renewable energy consumption in high-income and upper-middle-income countries; ii) In contrast, it diminishes renewable energy consumption in lower-middle-income countries; iii) Trade openness demonstrates insignificant effects on renewable energy consumption in low-income countries; iv) On the panel level, trade openness significantly and positively impacts renewable energy consumption. Our research underscores the significance of trade openness as a crucial instrument for advancing renewable energy development in high-income BRI countries, thereby fostering environmental sustainability. Policy interventions targeting renewable energy hold promise for enhancing environmental quality in low-income countries.

Keywords Trade openness · Renewable energy · BRI · GMM method · Diverse economies

Introduction

Trade openness around the world has expanded the volume of trade among countries. Economic growth and trade liberalisation have increased countries' energy use demand (Sun et al. 2019; Khan et al. 2021). It is generally accepted in the literature that trade positively impacts economic growth through technology transfer, spillovers, and productivity (Bonsu and Wang 2022). While trade openness increases economic growth, increasing energy consumption in this process may increase carbon dioxide (CO_2) emissions and worsen environmental quality (Khan et al. 2021). According to the United Nations (UN) (2022) report, global dependence on natural resources increased by more than 65% from 2000 to 2019. Energy-related CO_2 emissions rose by 6%, reaching their highest level ever in 2021 (UN 2022).

Energy scarcity, climate change, and global warming drive countries to develop low-carbon economies. This causes

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renewable energy to be considered an important alternative energy source (Omri and Nguyen 2014) and is central to achieving climate change and sustainable development goals for countries (Gu and Zhou 2020; Khan et al. 2021). Renewable energy is becoming more strategic in providing sustainable energy, especially for developing countries with large populations and no access to clean energy (Painuly 2001).

Between 2010 and 2019, total renewable energy consumption worldwide increased by a quarter, with the share of renewable energy in total final energy consumption rising to 16.3% in 2010, 17.0% in 2015, and 17.3% in 2017 (UN 2018). However, in 2019, the share of renewable energy in total final energy consumption remained at only 19% (UN 2022). According to BP (2022), Asia Pacific countries have the highest share of renewable energy consumption in 2021, with a share of 43.1%. Among the Asia–Pacific countries, China ranks first with 28.4% renewable energy consumption. In 2021, the regions with the lowest percentage of renewable energy consumption were the Commonwealth of Independent States (0.3%), the Middle East (0.4%), and Africa (1.2%) (BP 2022). While pursuing a green and low-carbon economy remains important for all countries (Sun et al. 2019), renewable energy use has not yet reached the desired level, especially in low-income and developing countries (Khan et al. 2021).

The United Nations (UN) announced the "2030 Sustainable Development Goals (SDGs)", with the main goals of ending poverty, combating inequality and injustice, and addressing climate change in 2015, and 17 goals were set to achieve sustainable development worldwide (UN 2022). Many SDGs, directly and indirectly, relate to clean and renewable energy and its impacts (Taghizadeh-Hesary and Yoshino 2020). For example, the UN 2030 SDG Goal 7 *Ensuring access to affordable, reliable, sustainable, and modern energy for all,* consists of aiming at providing universal access to affordable, reliable, and modern energy services, significantly increasing the share of renewable energy in the global energy mix, and doubling the global rate of improvement in energy efficiency by 2030. In this context, Target 7.a: By 2030, increase international cooperation to facilitate access to clean energy research and technologies, including renewable energy, energy efficiency, and advanced and cleaner fossil fuel technologies, and support investments in energy infrastructure and clean energy technologies, Target 7.b: By 2030, expand infrastructure and upgrade technologies in all developing countries, especially in less developed countries, small island developing countries, and landlocked developing countries, to provide modern and sustainable energy services for all. Sustainable Development Goal 13 aims to "take urgent action to combat climate change and its impacts" (Republic of Turkiye Presidency of Strategy and Budget 2021).

The Belt and Road Initiative (BRI), which was first proposed by Chinese President Xi Jinping in 2013, aims to jointly build the Silk Road Economic Belt and the 21st-Century Maritime Silk Road through eight key areas, including infrastructure, trade, investment, and ecological protection, all of which are in line with various SDGs, including SDG 7 on renewable energy and SDG 9 on infrastructure.

Energy plays a crucial role in the BRI project. In line with its commitment to the UN Climate Change Conference (COP21) in Paris, China's strategic goal is to reduce its dependence on coal. Decreased coal consumption means increased use of natural gas and renewable energy sources. BRI will facilitate China's access to energy resources with the content of new transportation corridors and commercial cooperation. In 2017, the National Development and Reform Commission (NDRC) and the National Energy Commission (NEA 2017) published a vision and action document[1] on energy cooperation under the BRI. The basic principles of this document are openness, mutual benefit, market orientation and respect for the environment. The document reaffirms its aim to increase energy security and integration for BRI countries while promoting the development of China's energy sector and diversification of its supply base and transportation routes. In 2013–2016, 70% of BRI projects were concentrated in the energy and infrastructure sectors. Leading the world in the field of energy technologies, China can accelerate the transition to sustainable energy sources in member countries with the BRI project.

The study contributes to the literature by examining the effects of a trade and development project that aims to change the direction of global trade, involving a large area and a large number of countries, on renewable energy use and thus on environmental quality and sustainable development, considering the income classification of countries. In this context, the study examines (i) the impact of trade openness, foreign direct investment, economic growth, and oil prices on renewable energy consumption in 94 countries included in the BRI project for the period 2000–2019 and (ii) whether the impact of trade openness on renewable energy consumption differs depending on the income level of countries.

The paper consists of six sections. After the introduction, in which the relationship between trade openness and renewable energy consumption is examined, the background of the BRI project is explained. In the third part, the literature review, the studies on the relationship between renewable energy and trade openness and the studies on the relationship between energy, economic growth and environment in BRI countries are summarised. Following the fourth section, which explains the model, dataset and hypotheses, the fifth section reports the methodology and empirical findings. The paper is completed with a conclusion, discussion and policy implications.

[1] Vision and Actions on Energy Cooperation in Jointly Building Silk Road Economic Belt and 21st Century Maritime Silk Road.

Background: Belt and road initiative (bri) project

The Belt and Road Initiative (BRI) is a project proposed by Chinese President Xi Jinping in Kazakhstan and Indonesia in 2013 for the joint construction of the Silk Road Economic Belt and the 21st-Century Maritime Silk Road (Dunford 2021) (Fig. 1). The BRI covers eight main areas: infrastructure, economic and trade cooperation, industrial investment, resource development, financial cooperation, cultural exchange, maritime cooperation, and ecological protection. These areas are also closely related to many of the goals and targets of the 2030 Agenda for Sustainable Development (see SDG Goal 7 on renewable energy; SDG Goal 9 pertains to infrastructure, SDG Goals 8 and 10 concern trade and finance, SDG Goal 14 deals with oceans and marine ecology). Of the sectors prioritised by the BRI, energy and transportation are particularly important (Wang-Nedopil 2022). The BRI comprises two main components: the Silk Road Economic Belt ("Belt") and the New Maritime Silk Road ("Road"), each supported by significant infrastructure investments (World Bank 2019). The first of these components is a land route to the west and east of China through three belts, and the second is a maritime route from the south of China to the Persian Gulf. BRI's road network consists of six corridors: 1-Mongolia-Russia Economic Corridor, 2-China-Central Asia-West Asia Economic Corridor, 3-China-Indochinese Peninsula Economic Corridor, 4-New Eurasian Land Bridge Economic Corridor, 5-Bangladesh-China-India-Myanmar Economic Corridor, and 6-China-Pakistan Economic Corridor (Aoyama 2016; World Bank 2019).

On the maritime route of the BRI, an economic corridor that connects the economies of the Association of Southeast Asian Nations (ASEAN), South Asia, West Asia, North Africa, and Europe is intended to be created. BRI is recently recognised as one of the most far-reaching collaborations between regions and countries. As of January 2021, the number of countries joining the BRI by signing Memorandums of Understanding (MoUs) with China increased from 140 to 147 as of March 2022. Of these countries, 43 are from Sub-Saharan Africa, 35 are from Europe and Central Asia (including the 18 European Union (EU) countries that are part of the BRI), 25 are from East Asia and the Pacific, 18 are from the Middle East and North America, 20 are from Latin America and the Caribbean, and six are from South Asia (https://greenfdc.org/countries-of-the-belt-and-road-initiative-bri/ as cited in Wang-Nedopil 2022).

According to 2019–2020 data, BRI covers 62.3% of the world's population, three-quarters of the world's energy resources, and 30% of the gross domestic product (GDP) (Athari and Ejazi 2020). Once completed, the BRI will bring together around 70% of the world's population. This population consists of countries that generate 55% of GDP globally and have about 75% of discovered reserves on their territory. The BRI initiative is estimated to increase global GDP to \$7.1 trillion by 2040, increase the GDP of 56 countries by more than \$10 billion by 2040 (CEBR 2019), and reduce global trade costs by up to 2.2% (Hillman et al. 2021). According to the World Bank (2019), trade is projected to grow by 1.7% to 6.2% globally and by 2.8% to 9.7% in the corridor economies (World Bank 2019). BRI allows Asian, African, and European countries to expand trade (Athari and Ejazi 2020). Of the countries included in the BRI project, 34 are high-income, 42 are high-middle-income, 41 are low-middle-income, and 30 are low-income (https://greenfdc.org/countries-of-the-belt-and-road-initiative-bri/, as cited in Wang-Nedopil 2022). Most of these countries are developing countries with a population of approximately 3 billion, accounting for 44% of the world's population (Harlan 2021), and a per capita income level of approximately USD 12,000. Although most BRI countries are in the developing country group, their infrastructure investments are low

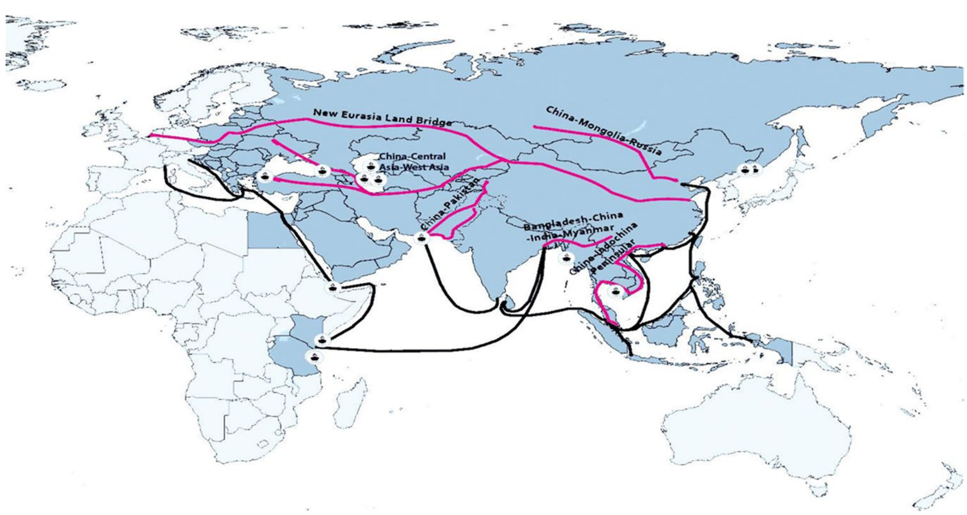

Fig. 1 The Silk Road Economic Belt and New Maritime Silk Road, World Bank (2019)

and ecologically fragile (Gu and Zhou 2020). According to 2019 data, 126 BRI countries, excluding China, account for approximately 28% of global carbon emissions. If the current carbon-intensive growth model continues, these percentages are expected to rise significantly over the next two decades (Baloch et al. 2019). In particular, because of the BRI's desired effects of increasing trade and investment and reducing travel times along the corridor (World Bank 2019), the increase in per capita income and economic growth in the countries involved in the project may lead to a rise in energy consumption and carbon emissions (Liu and Hao 2018). This raises environmental concerns about the BRI (Baloch et al. 2019). On the other hand, BRI countries are rich in renewable energy resources and have great potential for renewable energy development (Dong and Pan 2020). Furthermore, as the world's largest producer and consumer of renewable energy, China's renewable energy investments and cooperation with BRI countries are expected to play a positive role in achieving the host country's sustainable development goals and addressing climate change (Gu and Zhou 2020). However, renewable energy development and adoption in BRI countries is still in its infancy. As of 2018, the average share of renewable energy in total energy consumption in BRI countries was 9.48% (Dong and Pan 2020). Recently, the impact of BRI investment projects on society, economy, development, energy, and the environment has been one of the most remarkable issues. BRI investments can create serious challenges for the energy transition and climate change with large-scale fossil fuel investment projects. All these developments show that the success of the BRI in achieving the UN 2030 SDGs will be shaped by the policies that countries will adopt and implement.

Theoretical and empirical literature

The increase in trade between countries due to globalisation, economic integration, and direct investments has addressed the issue regarding trade openness, growth, energy, and the environment. In the literature, the relationship between trade (trade openness) and the environment is analysed under three effects: the scale effect, the composition effect, and the technological effect (Mutascu 2018; Farhani and Ozturk 2015; Sun et al. 2019). Similarly, trade openness affects energy demand through these three channels (Shahbaz et al. 2014). Increased trade, due to a reduction in trade barriers generally affects energy demand by expanding the scale of economic activity, changing the composition of economic activity, and leading to a change in production techniques (Grossman and Krueger 1991).

a. *The scale effect* refers to increased economic activity through trade that raises energy demand. Trade openness increases economic activity, domestic production, and economic growth. The increase in domestic production reshapes energy demand due to expanding domestic demand (Shahbaz et al. 2014; Zeren and Akkuş 2020).
b. *In the composition effect,* production processes are evaluated based on countries' comparative advantages (Sun et al. 2019). In the early stages of economic development, the sector that consumes the least energy dominates the economy. The shift of the structure toward the industrial sector with economic growth increases energy consumption. In the last stage of economic development, the service sector, which has low energy intensity and consumes less energy, gains weight (Shahbaz et al. 2014).
c. *In terms of technical impact,* international trade can be a channel for the diffusion of climate change mitigation technologies (solar energy, wind energy, biomass) from developed countries to developing countries. Technology adoption in developing countries reduces energy intensity, leading to lower energy use and higher output production (Shahbaz et al. 2014).

New collaborations and agreements to increase international trade can catalyse technological spillovers in developing and less developed economies, improving their weak renewable energy infrastructures. On the other hand, due to economies of scale and technological progress, the prices of equipment used in renewable energy generation have decreased significantly, pushing companies to explore new markets. This makes renewable energy more affordable for a broader range of consumers worldwide.[2] International technology transfer through trade also occurs when a country imports capital goods such as machinery and equipment to produce renewable energy (Jebli and Youssef 2015). Therefore, international trade is essential for transferring renewable energy technology and can play an important role in greening the energy sector.

While extensive literature examines the relationship between trade openness and environmental quality, the number of studies examining the relationship between trade openness and renewable energy consumption is limited. Table 1 summarises the findings of studies examining the relationship between trade openness and renewable energy consumption.

As seen in Table 1, studies examining the impact of trade openness on renewable energy use focus on a single country or group of countries (Yazdi and Shakouri 2017; Sulaiman et al. 2013; Ari and Cergibozan 2018; Han et al. 2022). However, the number of studies examining the relationship

[2] United Nations Environment Program. Renewable energy policy network for the 21st Century, ''Renewables 2013: Global Status Report''. Paris, France.2013. Accessed at:, http://www.ren21.net.

Table 1 Studies Examining Renewable Energy and Trade Openness Relationships

Authors	Country or Region	Methods and Models	Variables	Results
Sadorsky (2009)	G7 Countries	FMOLS, DOLS	RWC, PGDP, CO2, ROP	PGDP increases RWC—ROP decreases RWC
Pfeiffer and Mulder (2013)	108 developing countries	Two-stage estimation methods	RET, PGDP, TO, FDI	TO decreases RET—PGDP increases RET
Sulaiman et al. (2013)	Malaysia	GC	GDP, CO_2, TT, RWC	TT → RWC
Sebri and Ben-Salha (2014)	BRICS countries	ARDL, GC	GDP, CO_2, TT, RWC	TT ↔ RWC
Al-mulali et al. (2014)	18 Latin American countries	DOLS, GC	GDP, NRWC, L, C, TT	TT ↔ RWC
Aissa et al. (2014)	11African Countries	FMOLS, DOLS, GC	GDP, L, C, E, I, RWC	T does not affect RWC
Omri and Nguyen (2014)	64 Countries	GMM	GDP, CO_2, COP, TT, RWC	TO increases RWC / GDP increases RWC / COP decreases RWC
Jebli and Youssef (2015)	69 Countries	OLS, FMOLS, DOLS, GC	GDP, NRWC, E, I, RWC	T ↔ RWC
Akar (2016)	Balkan Countries	GMM	RWC, CO_2, GDP, TO, COP, NGP	TO increases RWC
Jebli et al. (2016)	25 OECD countries	FMOLS, DOLS, GC	GDP, CO_2, NRWC, E, I, RWC	E ↔ RWC /I ↔ RWC
Lin et al. (2016)	China	Johansen Cointegration, VECM	RWC,TO, PGDP,FDI,FI	PGDP increases RWC,TO and FDI decreases RWC
Tiba et al. (2016)	24 countries	GMM	GDP,TT, CO_2 RWC	TRA → REC in high income countries / TRA ↔ REC in middle income countries
Yazdi and Shakouri (2017)	Iran	ARDL, GC	GDP, EC, FD, TO, RWC	No causal link
Ari and Cergibozan (2018)	Turkiye	ARDL, GC	GDP, C, DC, TO, RWC	No causal link
Zafar et al. (2019)	18 emerging countries	Pedroni, Westerlund Cointegration, GC	GDP, CO_2, NRWC, RWC, TO	No causal link
Amri (2019)	23 developed countries 49 developing countries	GMM	GDP, C, TT, NRWC, RWC	There is a U-shaped relationship between TO and NRWC in developed countries and an inverted U-shaped relationship in developing countries
Zeren and Akkuş (2020)	Emerging economies	DHC, Westerlund Panel Cointegration Test, CCE-MG	RWC, NRWC, TO	NRWC increases TO, RWC decreases TO TO ≠ RWC
Murshed (2020)	71 low, lower-middle and upper- middle income countries	IV-2SLS	GDP, CO_2,FDI, CPI, COP, REM, ACFT, NODA, TO, RWC	TO decreases RWC in lower-middle income countries TO increases RWC in low-income countries
Alam and Murad (2020)	25 OECD countries	FMOLS, DOLS	GDP, TI, TT, RWC	TO increases RWC
Qamruzzaman and Jianguo (2020)	113 low, lower-middle and upper-middle income countries	NARDL, PMG,GMM	RWC, TO, FDI, FD	TO, FDI, FD increases RWC in lower-incomes FDI, FD increases RWC in middle incomes TO decreases RWC in middle income FDI, FD increases RWC in upper middle income
Zhang et al. (2021)	OECD countries	Panel Smooth Transition Regression Modelling	M, X, TT, GDP, FDI, CO_2, CPI, REM, RWC	M, X, TT, increases RWC
Li et al. (2021)	147 countries	OLS, FMOLS, Granger causality	PCO_2, PDGP, RWC, EI, TO, URB, ES	PGDP and EI increases PCO_2, RWC decreases PCO_2, PCO_2 ↔ PGDP, PCO_2 ↔ ES
Wang and Zhang (2021)	186 countries (high-income, upper-middle income, low-middle-income)	FMOLS	RWC,PGDP,T,TO, TX,POP	TO increases RWC at high and upper-middle income countries TO decreases RWC at lower-middle incomes GDP increases RWC

Table 1 (continued)

Authors	Country or Region	Methods and Models	Variables	Results
Ibrahiem and Hanafy(2021)	North African countries	Panel PMG, ARDL	RWC,TO,PGDP,FDI, CO2,EC,POP	TO increases RWC PGDP increases RWC FDI increases RWC
Wang et al. (2022a)	134 countries (high-income, upper-middle income, lower-middle income, low-income)	Threshold regression model	URB, PGDP, CO_2, EF, POP,RWC, NRR	An increases in URB strengthens the promotion effect of PGDP on CO_2 and EF, TO and NRR increases CO_2, POP and RWC decreases CO_2
Han et al. (2022)	China	Quantile Regression	GDP, URB, POP, TO, NRWC, RWC	TO partially increases RWC TO increases NRWC
Li et al. (2022a)	30 Chinese provinces	Threshold panel regression model	GRW, URB, EE, TCO_2,CT, PC	EE decreases TCO_2, URB decreases TCO_2,
Li et al. (2022b)	120 countries (high-income, upper-middle income, lower-middle income, low-income)	Threshold panel regression model	RWC, NRWC,PGDP, EF, EE, URB, POP	RWC increases PGDP and improves environment, NRWC increases PGDP, for different income groups RWC does not always suppress EF
Wang et al. (2023a)	56 countries (high-income, upper- middle income, lower-middle-income)	AMG, Panel threshold regression model	IQ, PGDP, URB, CO_2, EC, TO, INS	Economic growth has different impacts on carbon emissions in various income inequality ranges
Wang et al. (2023b)	208 countries	GMM, FMOLS	CO_2, PGDP, RWC, TO,HC, NRR	EKC is valid, TO, HC, NRR increases CO_2 RWC decreases CO_2

RWC: renewable energy consumption, NRWC: non- renewable energy consumption, RET: electricity generation from renewable resources, GDP: gross domestic product, PGDP: GDP per capita, GRW: income growth, TO: trade openness, COP: crude oil price, ROP: real oil price, NGP: natural gas price, URB: urbanisation, POP: population, EC:energy consumption, EI: energy intensity, EE: energy efficiency, EF: ecological footprint, M: import, X: export, TT: total trade, TX: trade taxes, REM: remittances, TI: technological innovation, FDI: foreign direct investment, CO_2: carbon emissions,PCO_2:per capita carbon emissions, TCO_2: transportation CO_2 emissions, CT: cargo turover,DC: domestic credit, CPI: inflation rate, L:labor, C: capital, FD: financial development, ACFT: access to clean fuel and technology for cooking, NODA: net official development assistance, HC: human capital, ES: economic structure, NRR: natural resource rent, IQ: income equality, INS: industrial structure, PC: number of private vehicles, EKC: Kuznets curve hypothesis, OLS: ordinary least squares, FMOLS: fully modified OLS, DOLS: dynamic OLS, ARDL: autoregressive distributed lag, NARDL: non-linear autoregressive distributed lag, 2SLS: instrumental variable two-stages least squares, AMG: augmented mean group, GMM: Dynamic panel system generalised method of moments DHC: DimutrescuHurlin causality, GC: Granger causality, PMG-ARDL: panel pooled mean group-autoregressive distributive lag; ↔: bidirectional causality, →:unidirectional causality between trade openness and renewable energy consumption by considering countries' income levels is quite limited (Murshed 2020; Qamruzzaman and Jianguo 2020; Amri 2019).

Studies on BRI address this issue from two perspectives. Some of these studies assess the opportunities and challenges of BRI in countries (Aoyama 2016; Brewster 2017; Zhang 2017; Lain 2018; Duarte 2018; World Bank 2019; Hoque and Tama 2020; He 2020; Harlan 2021; Dunford 2021; Ibrahim et al. 2021; Lai 2021). Another group of studies focuses on the impact of BRI on the economy, energy, and the environment. BRI countries' energy studies have mostly focused on non-renewable energy (Wu et al. 2020). The number of studies examining the UN 2030 SDGs' interaction with the BRI (Li and Zhu 2019; Lewis et al. 2021; Senadjki et al. 2022) is quite limited. Table 2 reports studies on the relationship between energy, economic growth, and the environment in BRI countries.

When generally evaluated, it is seen that the areas in which the impacts of BRI are analysed and the methods used in the analysis vary in studies on BRI. The findings of studies on renewable energy under the BRI also vary. For example, Dong and Pan (2020) argue that the energy structure is the primary driver of renewable energy consumption in BRI countries. Controlling fossil fuel use in these countries boosts renewable energy development. According to Geng (2021), the BRI project improves renewable energy development in the host countries. According to the findings, the scale of renewable energy in these countries, especially

Table 2 The Studies on the Relationship between Energy, Economic Growth and Environment in BRI Countries

Authors	Country or Region	Methods and Models	Variables	Results
Rauf et al. (2018)	49 countries	DOLS, FMOLS	CO_2, EC, GDP, FD, GFCF, UR, TO	EC, GFCF, GDP, FD, UR lead to CO_2, TO decreases CO_2, EC, GDP, FD, GFCF, UR $\leftrightarrow CO_2$, TO $\rightarrow CO_2$
Iqbal et al. (2019)	25 Asia countries	Panel data regression	GDP, X, M, FD, PS, Cor, FDI, CA, POP, CIP, BRI: BRI	BRI has a significant effect on GDP
Sun et al. (2019)	49 countries	Panel cointegration	GDP, EC, TO, CO_2	TO has mixed effect on CO_2 (increase and decrease)
Khan et al. (2020)	51 countries	Two-step D-SGMM and two-step D-DGMM	EC, GDP and CO_2 NR, TOU	It is important to allocate funds to green infrastructure EC $\leftrightarrow$ GDP, EC $\rightarrow CO_2$ TOU $\leftrightarrow$ GDP, TOU $\rightarrow CO_2$
Dong and Pan (2020)	BRI countries	Dynamic Panel, Convergence, LMDI Decomposition	RWC, UR, FDI, IND	B Convergence is valid for RWC in low-income countries
Hussain et al. (2021)	51 countries	Random-effects model, the fixed-effect model	RWCI, PGDP, TO, GOV	GDP increases RWI; TO increases RWI, GOV increases RWI
Wu et al. (2020)	178 nations and areas	Difference-in-Difference (DDD) and quantile DID methods	EF, UR, IND, PGDP, EC, TO, FDI, HC	BRI increases EF in resource-rich BRI countries than in resource-poor BRI countries BRI increases EF more in low-income BRI countries than those in high-income BRI countries
Wu et al. (2021)	97 countries	GMM	PCO_2, MI, EXI	MI decreases PCO_2, EXI increases PCO_2
Chen et al. (2021)	64 countries	Panel quantile regression approach	TO, CO_2	TO increases CO_2
Peng et al.(2021)	60 countries	β-convergence regression model	M, X, TEF	In high-income countries, T leads to TEF convergence

RWC: renewable energy consumption, RWCI: renewable energy investment, GDP: gross domestic product, PGDP: GDP per capita, M: import, X: export, T:trade, TO: trade openness, EC: energy consumption, FD: financial development, PS: political stability, Cor: corruption, FDI: foreign direct investment, CA: current account balance; POP: population, CPI: inflation rate, BRI: Belt and road initiative, CO_2: carbon emissions, PCO_2: per capita carbon emissions; EP: environmental pollution; NR: natural resources, TOU: tourism, UR: urbanisation, IND: industrialisation; GOV: governance, EF: energy efficiency, HC: human capital, MI: import intensity, EXI: export intensity, TEF: total factor energy efficiency, GFCF: Gross Fixed Capital Formation, DOLS: Dynamic panel estimations (dynamic ordinary least square), FMOLS: fully modified ordinary least square, GMM: Dynamic panel system generalised method of moments,

Table 3 Variable description and source of the dataset

Symbol	Variables	Description	Data Source
RWC	Renewable energy consumption	% of total final energy consumption	World Development Indicators (World Bank)
TRO	Trade Openness	Trade percentage of GDP	World Development Indicators (World Bank)
GDP	Economic growth	GDP per capita constant US$ 2015	World Development Indicators (World Bank)
FDI	Foreign Direct Investment	Net inflow percentage of GDP	World Development Indicators (World Bank)
COP	Crude oil price	Brent spot price (Dollars per barrel)	Energy Information Administration (EIA)

solar and wind energy is highly dependent on financing. The degree of technological development is based on the country's development needs and absorptive capacity. Renewable energy is influenced by the country's political and macroeconomic environment. Harlan (2021) emphasises that how green development is conceptualised and implemented in BRI is important and that green BRI projects do not exist, especially in low-income countries. It is important to examine the relationship between trade openness and renewable energy use in BRI countries, a global cooperation project in trade and investment between Asia-Europe economies that includes many developed and developing countries worldwide. The increased use of renewable energy through the Modern Silk Road project will play an important role in the low-carbon transformation of the world. Therefore, analysing the relationship between energy consumption and the trade cooperation that this project, which includes many developed, developing, and underdeveloped countries, aims to achieve will provide significant results for policymakers, researchers, and investors.

Theoretical framework and data

This study examines the impact of trade openness, foreign direct investments, crude oil prices and economic growth on renewable energy consumption in BRI countries. According to the availability of data, the empirical analysis covers the period 2000–2019 and 94 countries of BRI. The countries analysed in the model are divided into five main groups, four according to the World Bank classification based on per capita income and five BRI countries: low-income countries (LIC), low-middle-income countries (LMIC), upper-middle-income countries (UMIC), high-income countries (HIC), and finally all BRI countries.[3] The description, source, and unit of measurement of the data set used in the empirical analysis are reported in Table 3. The data's natural logarithmic form is considered for the analysis.

The model often includes trade openness as a control variable in studies examining the relationship between economic growth and carbon emissions. A few studies provide direct analyses of the trade openness-renewable energy relationship. In most studies on the determinants of renewable energy consumption, macroeconomic variables such as economic growth, energy consumption, financial development, foreign direct investment, urbanisation, population, and trade openness are included in the model (Sadorsky 2009; Pfeiffer and Mulder 2013; Omri and Nguyen 2014; Yazdi and Shakouri 2017; Murshed 2020; Li et al. 2021; Wang and Zhang 2021; Li et al. 2022b; Wang et al. 2022a; Wang et al. 2023b). In very few studies on the impact of trade openness on renewable energy, similar macroeconomic variables are included in the model (Zeren and Akkuş 2020; Han et al. 2022; Zhang et al. 2021; Alam and Murad 2020). In this context, the following model was constructed to determine the impact of trade openness on renewable energy use in the countries included in the BRI project:

$$LRWC_{it} = \beta_0 + \beta_1 LTRO_t + \beta_2 LGDP_t + \beta_3 LFDI_t + \beta_4 LCOP_t + \mu_t \quad (1)$$

where L is an indication of the natural logarithm, RWC denotes renewable energy consumption, TRO trade openness, GDP economic growth, FDI Foreign Direct Investment, and COP crude oil price (refer to Table 3).

Trade openness promotes commodity flow and economic output expansion between countries (Wang and Zhang 2021). The increase in trade due to a reduction in trade barriers generally affects the environment by expanding the scale of economic activity, changing the composition of economic activity and leading to a change in production techniques (Grossman and Krueger 1991). The effect of trade openness on the environment and energy use are still open questions due to differences in environmental costs across countries. Renewable energy is critical in supporting countries' efforts to combat climate change, achieve sustainable development goals, and ensure access to clean and reliable energy. As technology advances and economies of scale improve, renewable energy is becoming increasingly viable and strategic for building a sustainable energy source (Omri and Nguyen 2014; Gu and Zhou 2020; Painuly 2001). The foreign direct investment represents net investment

[3] Thecountries analyzed and their classification by income groups are reported in Table 7 (see appendix).

inflows to the host country. Two hypotheses regarding the impact of FDI on energy consumption are mentioned in the literature. First, the *pollution haven hypothesis* mentions the flow of dirty industries to developing countries due to strict environmental regulations in developed countries. This increases fossil fuel consumption and environmental destruction in the host country. Another hypothesis is the *pollution halo hypothesis.* According to this hypothesis, renewable energy use will increase in the host country as green technologies using renewable energy are transferred to the host country through FDI. Therefore, the impact of FDI on renewable energy use will vary depending on the type and form of investment. Most empirical studies on modelling energy consumption or energy demand consist of models that include the price of the energy itself, GDP per capita, and the price of the substitute energy source (Masih and Masih 1996; Sadorsky 2009; Karacan et al. 2021). Oil or oil-derived products are the most important substitutes for renewable energy. Therefore, crude oil prices are frequently used in empirical models to measure the cross-price elasticity between renewable and non-renewable energy sources.

On the other hand, the significant increase in oil prices, especially in recent years, and environmental problems such as global warming caused by greenhouse gas emissions, climate change, and the loss of biodiversity emphasise the importance of an alternative energy source to crude oil. Increasing per capita income improves people's living standards and enables them to purchase renewable energy sources. Therefore, oil prices and real GDP per capita are also included in the model as independent variables. In the literature, the relationship between income changes and environmental quality is called Environmental Kuznets. *The Environmental Kuznets Curve (EKC)* is an assumed relationship between various indicators of environmental degradation and per capita income. Environmental degradation and pollution increase in the early stages of economic growth, and this trend reverses after a certain level of per capita income (Stern 2004). Figure 2 represents the main hypotheses of the study.

In this context, the main hypotheses of the study are as follows (Fig. 2):

H_1: Trade openness increases renewable energy consumption. The first hypothesis tests whether trade openness increases renewable energy consumption in BRI countries classified by income level.

H_2: FDI increases renewable energy consumption. The second hypothesis tests whether the pollution halo hypothesis holds in BRI countries.

H_3: Oil Crude Prices increase renewable energy consumption. The third hypothesis tests whether a substitution effect exists between crude oil prices and renewable energy consumption.

H_4: GDP increases renewable energy consumption. The last hypothesis tests whether economic growth increases renewable energy consumption.

Econometric methodology and empirical results

Panel data can be estimated with several different alternative methods. One of the most commonly used methods is the fixed effects estimator. In the fixed effect (FE) model, the individual-specific coefficient for each individual is assumed to be constant in time (Gujarati 2021). Another panel data method is the random effects (RE) estimator. The RE method states that μ_i is a group-specific random element, except for a single drawback for each group that is regressed similarly in each period. The most important distinction between FE and RE is not whether the unobserved individual effect is stochastic but whether it includes elements associated with repressors in the model. The pooled ordinary least square (POLS) estimator is the weighted average of the between-group and within-group estimators. The F test used to choose between FE and POLS and has the null hypothesis of no individual or time effects, is performed on FE to test for the presence of unit effects. On the other hand, the Hausman Test, used to determine whether individual effects are fixed or random, allows us to distinguish between FE and RE.

In static panel data models, the use of lagged values of the dependent variable leads to the emergence of a relationship between the lagged values of the dependent variable

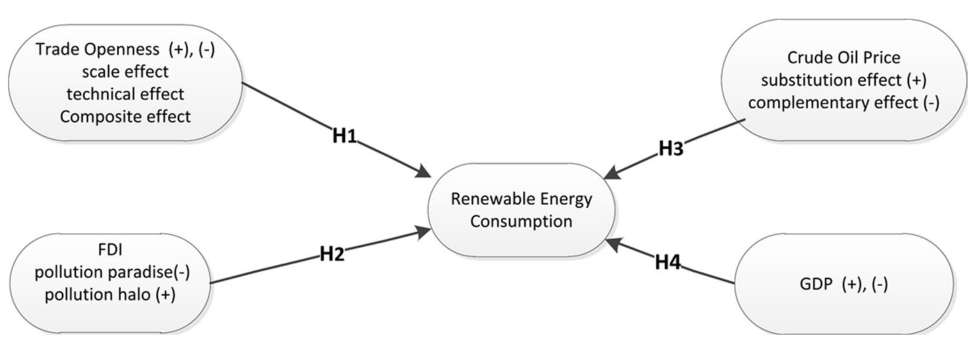

Fig. 2 Main hypotheses of the paper

and the error term, which leads to significant problems (Greene 2000). Thus, there are differences between dynamic panel models and fixed (FE) or random effects (RE) models (Greene 2000). In this context, Anderson and Hsiao (1981) suggest using lagged variables with different lag levels as instrumental variables. They emphasise that these lagged variables are correlated with the explanatory variables but cannot be correlated with the error term. With this type of instrumental variable method, the estimation of dynamic panel data models is consistent but inefficient estimators are obtained (Arellano and Bond 1991). The reason for the inefficiency of the estimators is that not all probabilistic instrumental variables are used. Therefore, using all lagged variables as instrumental variables in dynamic panel data models is recommended. Thus, dynamic panel system generalised method of moments (GMM) estimators, which eliminate differences in unobservable individual effects, use all possible lags of the dependent and independent variables as instrumental variables (Arellano and Bond 1991).

The difference GMM estimator of Arellano and Bond (1991) and the system GMM estimator developed by Arellano and Bover (1995) and Blundell and Bond (1998) are widely used as panel GMM methods in empirical studies. Dynamic panel data models are methods in which one or more explanatory variables are used as instrumental variables in the form of lagged endogenous variables (Guetat and Sridi 2017). These estimators are most appropriate when there is a linear functional relationship between them, the current value of the dependent variable is dependent on past values, and the independent variables are not strictly exogenous (Roodman 2009a). On the other hand, the GMM method can produce robust estimations for data sets that do not show a normal distribution and autocorrelation and heteroscedasticity problems. For this reason, it does not need unit root removal or various transformations to the series to show the normal distribution (Bağlıtaş 2019). The dynamic panel regression equation of the model analysed in the study is shown in Eq. 2.

$$\mathrm{LRWC_{it}} = \alpha \mathrm{LRWC_{i,t-1}} + \beta' \mathrm{X_{i,t}} + \eta_i + \mu_t + \varepsilon_{it} \quad i = 1, \ldots\ldots, N \quad t = 1, \ldots T_i \tag{2}$$

In Eq. 2, *LRWCit* denotes the renewable energy consumption of country i in period t, $\mathrm{LRWC_{i,\,t-1}}$ denotes the renewable energy consumption of country i. in period *t-1*, $\mathrm{X_{it}}$ denotes the other independent variables, i denotes the horizontal cross-sectional unit, t denotes the time dimension, and ε_{it} denotes the error term. η_i is the individual-specific effect and μ_t is the time-specific effect, accounting for unobserved heterogeneity across cross-sectional units.

Arellano and Bond (1991) proposed an estimation method considering unobserved heterogeneity and predetermined regressors. This method has good predictive power when the cross-section unit is larger than the time dimension (large N, small T) (Moral-Benito et al. 2018). This method requires taking the first difference of the regression to eliminate unobserved individual-specific effects (η_i) in the long-run regression. Due to this feature, the Arellano and Bond (1991) estimator is called the difference GMM method (Roodman 2009a). The first difference regression equation proposed by Arellano and Bond (1991) is shown in Eq. 3.

$$\begin{aligned} LRWC_{it} - LRWC_{i,t-1} = {} & \mu_t - \mu_{t-1} + \beta_1 LRWC_{i,t-1} \\ & + \beta_2 LTRO_{it} + \beta_3 LGDP_{it} + \beta_4 LCOP_{it} \\ & + \beta_5 LFDI_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

The difference GMM method has been criticised for biased results in small samples. If the variables are close to a random walk, lagged levels are generally poor tools for first differences (Gömleksiz and Özşahin 2019). Moreover, the difference GMM method in unbalanced panels exacerbates the missing data found in cross sections. (Roodman 2009a). In such cases, Arellano and Bover (1995) proposed the "*orthogonal deviations*" transformation to reduce data loss instead of the first difference transformation. This method is also called the system GMM estimator (sys-GMM). The System GMM method uses the lagged differences of the explanatory variables in the level equation. It proposes the lagged levels of the explanatory variables as instrumental variables in the first difference equation (Guetat and Sridi 2017). Briefly, the system GMM approach developed by Arellano and Bover (1995) combines the difference and level equations. Compared to the difference GMM, the system GMM approach allows for more instrumental variables and thus increases the estimation power (Roodman 2009a). If the variables are "random walk" or are close to being random walk variables, the system GMM is a more appropriate estimator. This is because the difference in the GMM estimator may suffer from a weak instrument variable (Sarafidis et al. 2009).

Furthermore, the system GMM is a more consistent estimator when series are persistent, lagged levels of variables are poor proxies for subsequent changes, and there is a dramatic reduction in finite sample bias due to the use of additional moment conditions (Blundell and Bond 1998; Blundell et al. 2001; Roodman 2009a). Finally, when working with unbalanced panel data, it is better to avoid the different GMM estimator, which has the weakness of missing data (Roodman 2009b). Since the dataset used in the study has been missing data for several years, the system GMM estimator is preferred in the study's empirical analysis. The consistency of the GMM estimator depends on the assumption that the error terms are not auto-correlated and that the instrumental variables are valid. These two assumptions must be tested with AR (2) and Sargan tests. The GMM method has also been used in previous studies (Omri and Nguyen 2014; Akar 2016; Tiba et al. 2016; Amri 2019; Wang et al. 2023b) to investigate the relationship between trade openness, economic growth and renewable energy.

The study analyses the data of 94 BRI member countries for the period 2000–2019. However, the impact of trade openness, economic growth, foreign direct investment and oil prices on renewable energy use may differ depending on the country's development level. For this purpose, the countries examined were grouped based on four different income levels, considering the World Bank's classification based on per capita income.

The impact of LTRO, LCOP, LGDP and LFDI on LRWC is heterogeneous across income levels. Table 4 shows the static and dynamic panel of high and upper-middle-income countries. According to the results of the F statistic and Hausman test statistic, the fixed effects method is the most appropriate estimator for high-income countries (compared to POLS and random effects). Therefore, only the results obtained from the fixed effects and sys-GMM estimator are discussed below.

Regarding the panel of *high-income* countries:

(i) The findings reveal that trade openness has a positive and statistically significant effect on renewable energy consumption. Similar conclusions have been documented in refs (Wang and Zhang 2021). Imports of capital goods between developed countries, such as machinery and equipment used in renewable energy production, provide technology transfer. This increases the consumption of renewable energy in these countries.

(ii) The findings indicate that the oil price is negative and statistically significant for high-income countries. This aligns with the Sadorsky (2009) and Omri and Nguyen (2014) results; according to the system, GMM results, oil price has an insignificant impact on LRWC. As mentioned by Omri and Nguyen (2014), the high ability of high-income countries to diversify away from oil price risk through derivative markets and appropriate energy conservation policies. In these countries, non-renewable and renewable energy are used together and show a complementary relationship.

(iii) LGDP also promotes renewable energy use in high-income countries (Sadorsky 2009; Omri and Nguyen 2014; Wang and Zhang 2021). This finding agrees with the expected impact of LGDP, as higher income levels exert more demand on the energy required for economic activities. Economic development can increase renewable energy consumption in different ways. First, with economic growth, the government can provide investment financing for environmental protection. Where basic development needs are primarily met,

Table 4 Results of Panel for High-Income and Upper-Middle-Income Countries

Variables	HIC				UMIC			
	POLS	FE	RE	Sys-GMM	POLS	FE	RE	Sys-GMM
LTRO	-0.812*** (0.000)	1.202*** (0.000)	1.074*** (0.000)	0.071* (0.067)	0.244 (0.146)	0.256*** (0.001)	0.258*** (0.001)	0.083*** (0.000)
LCOP	0.434** (0.016)	-0.057 (0.299)	-0.015 (0.770)	-0.028** (0.040)	-0.253* (0.053)	-0.111*** (0.000)	-0.112*** (0.000)	-0.065** (0.024)
LGDP	-1.402*** (0.000)	0.670*** (0.000)	0.544*** (0.000)	0.093** (0.031)	0.001*** (0.000)	1.352** (0.025)	1.467 (0.212)	1.171*** (0.000)
LFDI	0.151** (0.031)	0.050 ** (0.023)	0.053** (0.016)	0.003 (0.593)	0.249*** (0.000)	0.004 (0.783)	0.005 (0.723)	0.017* (0.062)
C	17.324*** (0.000)	-10.37*** (0.000)	-8.753*** (0.000)		1.348 (0.112)	1.488*** (0.000)	1.432*** (0.001)	
R^2	0.23	0.95	0.27		0.07	0.96	0.34	
$LRWC_{it-1}$				0.924 (0.000)				0.706*** (0.000)
Sargan Test				22.048 (0.396)				19.675 (0.478)
Hausman Test			28.002 (0.000)				3.384 (0.495)	
F Test		32.248 (0.000)				52.489 (0.000)		
AR_2				1.307 (0.191)				-1.5001 (0.133)
N				25				25
observations				500				500

POLS is ordinary least square, FE, RE, and sys-GMM are the fixed effects, random effects and system generalised method of moments respectively. ***, ** and * denote the significance level at %1, %5 and %10, respectively. p- values are given in the parentheses. HIC: high income countries, UMIC: upper-middle income countries. N: cross-section size. Null hypothesis for F test: there are no individual and time effects the government will act to promote energy efficiency while promoting renewable energy. Second, because of increased income level and improved living standards, people will demand environmental protection and be willing to use environmentally friendly technologies such as renewable energy.

(iv) According to fixed effect results LFDI has a positive impact LRWC. In this income group, the pollution halo hypothesis is valid.

According to the F and Hausman test results for the upper-middle income group, the most appropriate estimator for our model is the random effects estimator (compared POLS and fixed effects). Thus, only the results obtained from the random effects and sys-GMM estimator are discussed below.

For the upper-middle income panel,

i) This finding indicates that LTRO, LGDP and LFDI have positive and statistically significant effects on LRWC.
ii) According to random effect and system GMM results, renewable energy is negatively affected by oil prices in upper-middle-income countries. This aligns with Sadorsky's (2009) and Omri and Nguyen (2014) results. This result suggests that crude oil and renewable energy are complements and are not substitutes for consumption. It means that energy users consume crude oil and renewable energy together.
iii) LGDP promotes the use of renewable energy. A similar result was found by Wang and Zhang (2021).
iv) According to System GMM, the findings reveal that LFDI has a positive and significant but negligible effect on LRWC. This agrees with the results of Qamruzzaman and Jianguo (2020) and Ibrahiem and Hanafy (2021). Direct investments can positively impact renewable energy development through technology transfer and capabilities.

The results of the panel analysis for lower-middle-income and low-income countries are reported in Table 5. The F test and Hausman test results for lower-middle-income and low-income countries show that the random effect estimator is an effective estimator for the model (compared to POLS and fixed effects). Therefore, only random effects and sys-GMM results are interpreted.

i) For the lower-middle income counties, LTRO negatively and significantly affects LRWC. Similar results were found by (Pfeiffer and Mulder 2013; Lin et al. 2016; Murshed 2020; Wang and Zhang 2021). However, these results are inconsistent with Omri and Nguyen (2014). For lower-middle-income countries, increasing trade

Table 5 Results of Panel for Lower-Middle Income and Low-Income Countries

Variables	LMIC				LIC			
	POLS	FE	RE	Sys-GMM	POLS	FE	RE	Sys-GMM
LTRO	-0.305*** (0.000)	-0.064* (0.067)	-0.067** (0.048)	-0.015** (0.017)	-0.104** (0.022)	-0.005 (0.616)	0.014 (0.374)	0.017 (0.323)
LCOP	0.141 (0.116)	0.014 (0.592)	0.017 (0.524)	0.008*** (0.000)	0.020 (0.377)	0.009* (0.068)	0.0012 (0.882)	0.002 (0.504)
LGDP	-0.005*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-2.132*** (0.000)	-0.295*** (0.000)	-0.224*** (0.000)	-2.265*** (0.000)	-0.035** (0.023)
LFDI	0.050 (0.277)	-0.029* (0.062)	-0.029* (0.063)	-0.0012 (0.518)	-0.0012 (0.874)	-0.004*** (0.008)	-0.0023** (0.043)	-0.0048 (0.345)
C	5.038*** (0.000)	3.939*** (0.000)	3.970*** (0.000)		6.586*** (0.000)	5.773*** (0.000)	5.992*** (0.000)	
R^2	0.21	0.94	0.28		0.32	0.92	0.36	
$LRWC_{it-1}$				0.979 (0.000)				0.895 (0.000)
Sargan Test				22.938 (0.523)				11.048 (0.439)
Hausman Test			3.101 (0.541)				1.638 (0.801)	
F Test		263.354 (0.000)				203.230 (0.000)		
AR_2				1.239 (0.215)				0.002 (0.998)
N				28				16
observations				560				320

POLS is ordinary least square, FE, RE, and sys-GMM are the fixed effects, random effects and system generalised method of moments, respectively. ***, ** and * denote the significance level at %1, %5 and %10, respectively. p- values are given in the parentheses. LMIC: lower-middle income countries, LIC: low income countries. N: cross-section size volumes will reduce renewable energy consumption. This result indicates that these countries' production and export structures are predominantly based on non-renewable rather than renewable energy inputs. In lower-middle-income economies, reasons such as the lack of skilled labour, weak infrastructure, and inadequate technological knowledge and resources make the transition from fossil fuels to renewable energy consumption difficult. Eliminating trade barriers, new international cooperation and trade agreements increase the pressure on energy demand. Especially low-income countries that have problems with renewable energy technology tend to meet their increasing energy demand from fossil fuels.

ii) The effect of LGDP on LRWC is negative. The Environmental Kuznets Curve (EKC) expresses an inverted U-shaped relationship between growth and environmental quality and says that up to a threshold level of economic growth will increase the use of traditional fossil fuels. Carbon emissions caused by fossil fuels decrease after this threshold level of growth. In low and middle-income countries, the manufacturing industry sector is predominant. Therefore, these countries' economic growth is based on fossil rather than renewable energy.

iii) According to the random effects results, LFDI has a negative effect on renewable energy consumption. This aligns with the results of Lin et al. (2016) and Ibrahiem and Hanafy (2021). Therefore, foreign investments in these countries are investments in dirty industries rather than green energy, and the pollution haven hypothesis is valid in these countries.

iv) According to the random effects and sys-GMM results in low-income countries, trade openness and oil prices do not significantly affect renewable energy consumption. In low-income countries, the production of commercial products is primarily based on fossil fuels. On the other hand, the lack of technological infrastructure, knowledge and skills makes reaching renewable energy sources in these countries difficult.

v) The result indicates that LGDP has a negative and statistically significant effect on renewable energy consumption in low-income countries.

vi) According to the random effects and sys-GMM results, LFDI seems to have a negative but very low effect level.

According to the fixed effects and sys-GMM for the panel, trade openness positively and significantly affects renewable sources. This is in line with the results of Pfeiffer and Mulder (2013), Omri and Nguyen (2014), Akar (2016), Alam and Murad (2020), Wang and Zhang (2021), Ibrahiem and Hanafy (2021), Hussain et al. (2021), Han et al. (2022). "Imports of capital goods such as machinery and equipment used in renewable energy production between countries provide technology transfer. This increases renewable energy consumption in these countries". This result indicates that the trade openness contributes to obtaining clean technology and knowledge that promotes the expansion of renewable energy capacity". For the panel, the finding shows that the technique effect is valid (Table 6).

The findings reveal that LGDP negatively and statistically significantly impacts LRWC. Refs have documented similar conclusions (Akar 2016; Ergun et al. 2019). However, the general opinion in the literature is that economic growth increases renewable energy consumption (Sadorsky 2009; Pfeiffer and Mulder 2013; Lin et al. 2016; Wang and Zhang 2021; İbrahiem and Hanafy 2021; Hussain et al. 2021). And also Wang et al. (2022b) found a positive relationship between renewable energy and economic growth in 104 selected countries.

Increasing economic growth can reduce renewable energy consumption in countries where energy is imported mostly and mainly dependent on non-renewable energy sources. For these countries, renewable energy technologies are costlier than fossil fuels. This situation causes the continuation of non-renewable energy consumption. To afford the costs of renewable energy technologies, a country must reach a certain level of economic growth and development.

This result is not unexpected because most of the 94 countries examined in the panel are low- and middle-income countries. According to the System GMM results, oil prices (LCOP) affect renewable energy consumption positively (similar to Sadorsky 2009; Omri and Nguyen 2014) but at a negligible level. The findings indicate that FDI negatively and statistically significantly impacts RWC. This is in line with the results of Lin et al. (2016). While direct investments may positively affect renewable energy development, they may not increase the total share of renewable energy consumption. This may be because direct investments heavily prioritise cheap and subsidised fossil fuels. The pollution haven hypothesis can also explain this result.

Conclusions

The association between trade openness, economic growth, foreign direct investment and energy has been a significant concern for researchers and policymakers in developed and developing countries. These factors are likely to positively or negatively affect environmental quality through different channels. Some researchers argue that these factors positively affect environmental quality due to technology transfer, learning by doing, talent diffusion and efficiency. On the other hand, the quality of the environment is deteriorating due to increased trade openness and foreign direct investment in developing countries because of poor environmental policies. At this point, renewable energy is critical in achieving sustainable energy supply, environment quality, and climate change goals. In 2015, "The 2030 Sustainable Development Goals (SDG)" was declared by the UN to

Table 6 Results of Panel for BRI Countries

Variables	Panel			
	POLS	FE	RE	Sys-GMM
LTRO	-0.385*** (0.000)	0.101*** (0.002)	0.081** (0.015)	0.115*** (0.00)
LCOP	0.144** (0.023)	0.005 (0.759)	0.033* (0.059)	0.003*** (0.000)
LGDP	-0.704*** (0.000)	-0.004 (0.992)	-0.117*** (0.003)	-0.0034*** (0.000)
LFDI	0.091*** (0.001)	-0.034*** (0.000)	-0.035*** (0.000)	-0.024*** (0.000)
C	9.614*** (0.000)	2.384*** (0.000)	3.301*** (0.000)	
R^2	0.34	0.96	0.14	
$LRWC_{it-1}$				0.912 (0.000)
Sargan Test				96.312 (0.414)
Hausman Test			57.698 (0.000)	
F Test		325.947 (0.000)		
AR_2				0.723 (0.469)
N				94
observations				1980

POLS is ordinary least square, FE, RE and sys-GMM are the fixed effects, random effects and system generalised method of moments, respectively. ***, ** and * denote the significance level at %1, %5 and %10, respectively. p- values are given in theparentheses

combat climate change (UN 2022). Particularly, Sustainable Development Goals 7 and 8, which are compatible with economic stability and environmental sustainability, play an important role in the issue of climate change. A significant portion of the SDGs relate directly and indirectly to clean and renewable energy and its impacts.

Today's world is characterised by increased globalisation and intensification of economic cooperation between regions. One of the most comprehensive agreements in recent times is the BRI, launched by China in 2013 (Chen et al. 2021). The BRI is considered a very comprehensive project in terms of "policy dialogue", "infrastructure connection", "barrier-free trade", "financial support", and "interpersonal exchange" in ensuring cooperation between countries (Huang 2016). It is observed that the priority areas determined by BRI and most of the goals and objectives of the UN 2030 Agenda for Sustainable Development are related. For instance, as Wang-Nedopil (2022) mentioned, approximately USD 60.5 billion of financing and investments were made in 2020 under the BRI. In 2020, while the amount related to oil to that financing and investments was 1.9 billion USD, green energy financing and investments amounted to 6.2 billion USD. In 2021, the respective values were realised as 6.4 billion USD and 6.3 billion USD, respectively. Countries in the BRI corridor account for the bulk of global economic output, trade and investment. According to estimations, the BRI initiative can increase global GDP to $7.1 trillion by 2040, increase the GDP of 56 countries by more than $10 billion by 2040 (CEBR 2019), and reduce global trade costs by up to 2.2% (Hillman et al. 2021). Especially, BRI is seen as an opportunity to expand trade between Asian, African and European countries. According to the World Bank (2019), trade is expected to grow between 1.7% and 6.2% worldwide and between 2.8% and 9.7% for corridor economies. As a result of the BRI initiatives, the rise in economic growth and trade volume in these countries will increase energy demand and affect environmental quality. However, most BRI countries are developing and underdeveloped and ecologically fragile countries. This raises environmental concerns about BRI.

This study proposes a static and dynamic panel data model to estimate the impact of trade openness, oil prices, economic growth and foreign direct investment on renewable energy consumption. Also, we selected 2000–2019 data from 94 BRI countries with different income levels (high-, upper-middle-, lower-middle, and low-income panels) to establish the model.

Our main findings show:

i) Trade openness favourably and statistically affects renewable energy consumption in high-income, upper-middle-income, and panel nations. Conversely, trade openness has a detrimental effect on using renewable energy in low- and middle-income countries.
ii) Oil prices significantly and negatively affect renewable energy consumption in high-income and upper-middle-income countries. However, the impact of oil prices on

renewable consumption is positive and significant for lower-middle and panel countries.

iii) The impact of GDP on renewable energy consumption is also heterogeneous. For high-income and upper-middle-income countries, the increase in GDP has a positive and significant effect on renewable energy consumption. The effect is significant and negative for lower-middle-income, low-income, and panel countries.

iv) The changes in foreign direct investment have a statistically significant and positive impact on high-income, upper-middle-income countries. Conversely, it has a negative impact on renewable energy consumption in lower-middle-income, low-income and panel countries.

An essential international project, the BRI has evolved to foster infrastructure growth, commerce, and economic cooperation between China and countries in Asia, Europe, and Africa. This paper investigates how the BRI project has affected the use of renewable energy across various socioeconomic levels. Our research indicates that high-income, upper-middle-income, and panel countries of the BRI benefit from free trade in renewable energy consumption. Trade openness typically encourages using environmentally friendly energy as nations' wealth levels rise. However, it is challenging to say similar things for low-income countries with serious problems, even in terms of access to electricity. The empirical results of our study on low-income and lower-middle-income countries differ from the findings of some studies in the literature. (Amri 2017; Sebri and Ben-Salha 2014; Omri and Nguyen 2014; Qamruzzaman and Jianguo 2020). The findings of our study highlight the need for the BRI initiative to develop different policies for low-income countries to achieve their green development goal. Also, countries with low economic levels tend to consume non-renewable energy, which draws attention to the difficulties of transitioning to cleaner energy sources without the necessary infrastructure and investment. Finally, our study focuses on the BRI initiative's potential to spur sustainable growth and encourage the use of greener energy sources.

Discussion and Policy Implications

The BRI initiative to boost economic growth in a wide area stretching from the southern coast of China to Africa covers more than 110 countries. China aims to transfer enormous investments to this region to connect the region with the Silk Road Belt and Maritime Silk Road and to open new markets. Opening new transportation routes, ports and railways within the project's scope reduces logistics costs. China, the world's largest exporter of renewable energy equipment, can export more renewable energy technologies to high-income countries with strict environmental regulations with this reduction in logistics costs. Similarly, the cost advantage increases the renewable energy equipment demands of high-income countries and, therefore, the use of renewable energy. However, the BRI initiative's environmental impact may harm low-income countries. In the last few years, Chinese companies have invested heavily in coal power in low-income BRI countries. With this project, China paves the way for establishing coal power plants that will be enough for developing countries for years. These investments slow the transition to renewable energy sources in low-income countries that ignore environmental pollution for economic growth and development.

According to the Global Environment Institute (GEI) research, China took part in 240 coal power plant projects with a total production capacity of 251 gigawatts in BRI countries between 2001–2016. For low-income BRI countries, coal power remains attractive as the most viable way to expand energy accessibility. The Asian Infrastructure Investment Bank (AIIB) estimates that 460 million people in Asia still lack electricity access. The situation creates an urgent need to meet local energy demands, overshadowing climate change and local pollution concerns (OECD 2018).

According to the empirical findings of this paper, countries participating in the BRI are more likely to adopt clean energy sources and technologies as their economic levels increase. In this context, China's shifting of energy investments in low-income BRI countries from coal projects to low-carbon alternatives will contribute to the sustainable development of the countries in the region and expand China's global green energy investment environment. For that purpose, companies investing in green energy in low-income BRI countries may be incentivised by both the host country and the Chinese government. On the other hand, low-income countries should establish an alternative cost relationship between economic growth and environmental destruction and review their environmental policies. Additionally, global initiatives to prevent climate change and environmental pollution must take binding steps to provide technological and financial support to low-income countries in the transition to green energy.

The paper has limitations, including the absence of important factors such as governance and tourism that could impact the relationship between the BRI program and sustainable energy use. Future studies should examine these factors in more detail to provide a more complete understanding of the potential impacts of BRI efforts on sustainable development. This paper examined the impact of the BRI initiative on renewable energy use in countries with different income groups. However, the impact of increased international trade with the BRI initiative on the environmental quality of member countries has not been determined. Since the BRI initiative covers both the Silk Road Belt and the Maritime Silk Road, its impact on soil, air or sea pollution can be analysed separately. In addition, different econometric and statistical methods that consider the heterogeneity between countries and can give individual results can be used. Researchers in the future could leverage and consider these limitations.

Appendix

Table 7 Note: This data is mandatory, Please provide

Low Income (16)	Lower-Middle Income (28)	Upper-Middle Income (25)	High Income (25)
Burundi	Angola	Botswana	Seychelles
Chad	Cabo Verde	Ecuador	Cyprus
Congo, Dem. Rep	Cameroon	Gabon	Czechia
Gambia, The	Ghana	Namibia	Estonia
Guinea	Kenya	South Africa	Greece
Madagascar	Nigeria	Armenia	Hungary
Mali	Sudan	Azerbaijan	Italy
Mozambique	Zambia	Belarus	Lithuania
Senegal	Georgia	Bosnia and Herzegovina	Latvia
Sierra Leone	Kyrgyz Republic	Bulgaria	Luxembourg
Tanzania	Moldova	Kazakhstan	Poland
Togo	Mongolia	North Macedonia	Portugal
Uganda	Ukraine	Romania	Slovak Republic
Zimbabwe	Uzbekistan	Turkiye	Slovenia
Tajikistan	Cambodia	China	Korea Republic
Nepal	Indonesia	Fiji	New Zealand
	Kiribati	Malaysia	Singapore
	Philippines	Thailand	Malta
	Solomon Islands	Tonga	Qatar
	Vietnam	Algeria	Saudi Arabia
	Vanuatu	Iran	United Arab Emirates
	Morocco	Irag	Barbados
	Tunisia	Lebanon	Chile
	Bolivia	Costa Rica	Panama
	Egypt	Peru	Uruguay
	El Salvador		
	Bangladesh		
	Pakistan		

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