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ENHANCING HUMAN DEVELOPMENT IN G7: INSIGHTS FROM RENEWABLE ENERGY CONSUMPTION, MULTIFACTOR PRODUCTIVITY, SHADOW ECONOMY BY APPLYING THE ADVANCED PANEL QUANTILE DATA METHOD

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Abstract

Countries' economies are facing challenges in revitalizing and redesigning their economic systems to enhance human development and environmental compatibility. By using the Method of Moments quantile technique, this study explores the heterogeneous impacts of renewable energy consumption, multifactor productivity and shadow economy on human development index (HDI) in Group of Seven countries from 1991 to 2018. In the panel quantile examination, results revealed that an increase in renewable energy consumption and multifactor productivity significantly contributes to HDI. In contrast, empirical results show that the shadow economy reduces HDI. Our analysis reveals a bidirectional causality observed between HDI and shadow economy and the unidirectional causality influence of HDI on renewable energy consumption and multifactor productivity. The research results provide some suggestions for policymakers on strengthening the role of renewable energy and multifactor productivity and reducing the underground economy's harmful effects on human development.

Keywords: Human Development Index; Renewable Energy Consumption; Multifactor Productivity; Shadow Economy; Method of Moments Quantile Regression.

1. INTRODUCTION

Human society has reached a highly developed state, but we have caused the earth to face many serious problems. The pressure we place on the planet is greater than ever. Climate change, environmental pollution, conflicts and crises are having an increasingly large direct or indirect impact on all individuals across the globe (UNDP, 2020, 2022). Besides, the global economy faces challenges related to structure and efficiency (Doğan, Ghosh, et al., 2022; UNDP, 2014), increasing energy demand (X. Yang & Khan, 2021), environmental degradation caused by non-renewable energy (Nan et al., 2022) and new uncertainty complex (UNDP, 2022). These enormous challenges are profoundly impacting the foundations of human society. Hence, nations are presently endeavouring to progress towards sustainable development. Accordingly, numerous countries are actively seeking to attain 17 sustainable development goals (SDGs) (Tucho & Kumsa,

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2020). The primary objective of the sustainable development goals (SDGs) is to guarantee the well-being and satisfaction of all individuals, while also promoting economic, social, and technical advancements that are in alignment with the natural environment (UN, 2015). Therefore, sustainable development goals and human development are closely linked. Since 1990, the United Nations Development Programme (UNDP) has used the Human Development Index (HDI) to measure nations' human development (Çakar et al., 2021; Hirai, 2017; Ranis et al., 2006; Sinha & Sengupta, 2019; UNDP, 1990). The HDI serves as a comprehensive measure that evaluates achievements in three basic dimensions (health, education and living standards) of human development rather than solely focusing on the economic growth of a specific nation (UNDP, 2019). At present, it is a widely accepted indicator of the level of human well-being in various countries. Therefore, the HDI is not only an indicator-based assessment to determine sustainability (Phillips, 2023), but the HDI also plays a vital role in guiding countries to develop their corresponding development strategies. However, HDI content does not fully reflect environmental issues (Biggeri & Mauro, 2018; Hirai, 2017; Ranis et al., 2006). The human development process is now not simply based on the results of the economic development; sustainable and balanced human development is also based on the effectiveness of solving crises of socio-economic and environment. Therefore, the defining factors of human development cannot be narrowed but must be studied extensively.

Meanwhile, the modern economy in the era of industrialization and globalization has promoted energy consumption worldwide. However, the economic activities of many countries rely heavily on non-renewable energy sources, which leads to environmental degradation (Ahmad et al., 2021; Z. Ahmed & Le, 2020; Baloch et al., 2021). In addition, non-renewable energy sources are increasingly depleted and unsustainable (Aboul-atta & Rashed, 2021; Y. Xu & Zhao, 2023). Consequently, the world’s economy shifted energy consumption towards renewable energy sources. Energy transition renewable energy sources is the process of shifting to more sustainable and environmentally friendly energy sources (Hu et al., 2022; W. Li et al., 2023). Renewable energy naturally uses additional sources, such as sunlight, wind, oceans, hydro and geothermal, which can optimize energy use and promote wellness of the environment by reducing greenhouse gas emissions and climate change (Chu et al., 2023). The proportion of renewable energy in worldwide electricity generation increased to approximately 28% in 2020 (IEA, 2020), which reduces global carbon dioxide emissions by millions of tons (R. Li et al., 2022). Renewable energy promotion is essential for sustainable development due to its environmentally friendly nature (Z. Li et al., 2022). Renewable energy closely impacts on human development worldwide (Haseeb et al., 2023; Martínez & Ebenhack, 2008). Hence, several studies have elevated the importance of renewables on human development in developed and developing countries worldwide (Wang et al., 2018).

According to economic theory, productivity is an essential measure of the economy's situation at different levels. Over the last few decades, productivity has been important because increased productivity reflects the ability to produce more output. In particular, productivity reflects the efficiency of using all resources of the economy. A single input

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factor can determine productivity. Labor productivity is an example of a single-factor input that may be used to describe productivity. At the beginning of the XXI century, total productivity and multifactor productivity have been utilised as metrics to assess the productive capability of an economy. Multifactor productivity (or total factor productivity) defines productivity in terms of several or all factor inputs. Multifactor productivity estimates the residual output growth that cannot be explained by input changes such as capital and labour (OECD, 2016). Total factor productivity is calculated by combining the impacts of all used resources in the manufacturing process and dividing this value by the output (Filipenko, 2021). Multifactor productivity may be estimated at various levels, including the economy, industry or the economic sector. Multifactor productivity, or residual output, is also considered as the specifications determining the cause of economic growth. Therefore, multifactor productivity is an important parameter responsible for a significant proportion of differences in economic development among countries. Increasing multifactor productivity can increase efficiency, improve competitiveness, enhance innovation, increase employee satisfaction, and increase economic growth. Improving productivity via technological and human capital advancements is crucial in uplifting people's living standards (T. Ahmed & Bhatti, 2020). Similarly, Isaksson (Isaksson, 2007) also argued that total factor productivity growth affords society the opportunity to improve the well-being of people. Thus, multifactor productivity is closely related to the basic elements of human development. However, traditional total factor productivity frameworks that do not consider energy consumption and environmental emissions are becoming increasingly unsuitable for sustainable growth and will result in inaccurate total factor productivity estimations (Cárdenas Rodríguez et al., 2018; Yue et al., 2019). Similarly, multifactor productivity ignores emissions and natural resource consumption (H. Yang et al., 2021). Multifactor productivity is a complex concept with many aspects influenced by various policies and institutions. Therefore, the role of multifactor productivity in the human development process needs to be further explored.

The shadow economy, with other names such as informal economy, black economy, underground economy or hidden economy (Frank Wu & Schneider, 2019), has long been acknowledged as a remarkable phenomenon in economies, posing a wide variety of potentially severe policy challenges for social and material well-being. In reality, the shadow economy is difficult to determine due to its informal nature (Alm & Embaye, 2013). Shadow economy refers to economic activities and transactions that are either illicit or unreported to authorities (Alvarado et al., 2021). In basic terms, the shadow economy refers to economic activities that are not officially recorded or acknowledged by governments (Nguyen & Nguyen, 2023). These can take the form of black markets, underground economies, or informal economies. Despite more robust economic growth and employment creation, the extent of the shadow economy in nations has remained high or increased (T. H. H. Pham, 2017) because workers may choose informal employment for various reasons, depending on the situation of their location as well as their personal characteristics (Ohnsorge, Franziska, 2022). The informal economy is linked to greater poverty and income inequality (Alvarado et al., 2021). Because, on a

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typical basis, economies with higher informal economy sectors have less access to private sector financing, lower productivity, delayed accumulation of physical and human capital, less educated labor forces, and fewer fiscal resources (Ohnsorge, Franziska, 2022). Consequently, adverse macroeconomic and development outcomes are commonly associated with a substantial informal sector (Elgin et al., 2021). Furthermore, the shadow economy is intrinsically linked to environmental degradation (Pang et al., 2021) as it poses a significant danger to environmental security (Qayyum et al., 2021) and impedes nations' endeavours to enhance energy efficiency (Chen et al., 2021). Thus, the underground economy is bringing distortions to the economy. The consequence of the underground economy is that macroeconomic management becomes ineffective. These factors affect the equity, ecological environment and well-being of nations. Hence, for developed nations to achieve their sustainable development goals, it is important to consider considering shadow activities (Saafi et al., 2023).

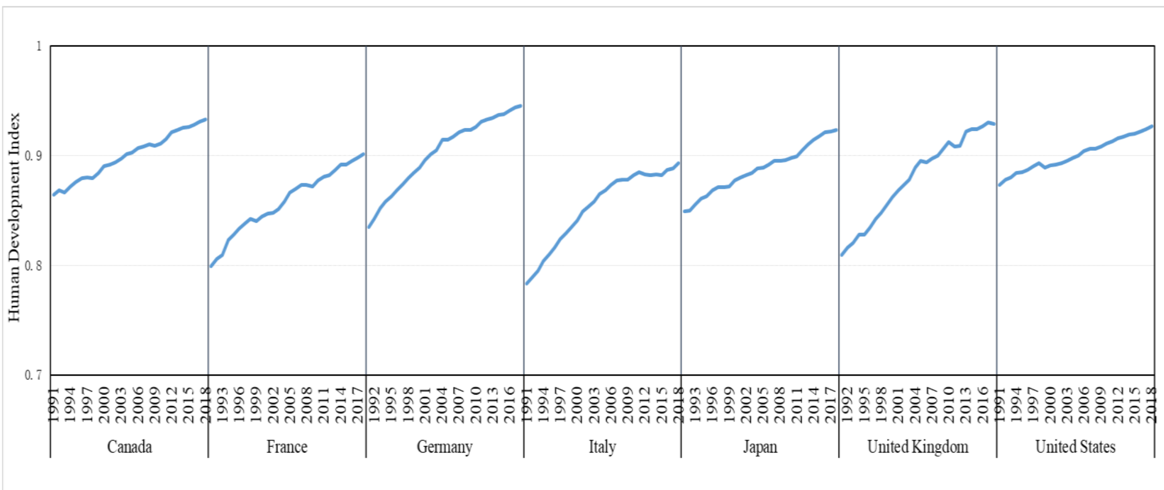

Fig. 1. Trends in the Human Development Index of G7 countries, 1991–2018.

The Group of Seven (G7: Canada, France, Germany, Italy, Japan, the United States and the United Kingdom) accounts for about 44% of the global economy in nominal terms. At the same time, the HDI index of G7 countries, as illustrated in Fig. 1, has grown significantly over the years, showing significant successes in human development progress in this group of countries. Developed countries have focused on environmental protection as they have achieved high economic prosperity (Akram et al., 2020). The G7 countries are actively transitioning energy use towards green, clean and environmentally friendly (Doğan, Chu, et al., 2022; Ibrahim et al., 2023). Particularly for the G7 group, from 1995 to 2015, the proportion of renewable energy increased by 2.5 times on average (Z. Khan et al., 2020). However, The G7 countries have yet to make a tangible impact in achieving the 7th and 13th SDGs (D. Xu et al., 2022). The G7 countries continue to face increasing ecological footprints (Ahmad et al., 2021), leading to concerns about environmental pollution and the ability to achieve sustainable development goals in these countries (Z. Ahmed et al., 2022). In recent decades, enhancing productivity has been a

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basic and important objective of G7 economies. Since 1970, all advanced economies converged to the highest productivity levels. The second industrial and information technology revolutions are believed to have driven increased productivity growth in developed economies (Bergeaud et al., 2016). However, the productivity slowdown since the 2007-2009 crisis has been steep and prolonged.

The slowdown in productivity growth in developed countries is due to many factors, such as the global financial crisis, COVID-19, barriers to competition and unequal educational and work opportunities. Besides, the underground economy does not only exist in developing economies but also developed economies.

The underground economy still accounts for a significant proportion of the G7 countries, with an average of over 10% from 1991 to 2018. The fact that the members of the G7 are all developed economies does not mean that these economies are not affected by the shadow economy. Fig. 2 shows the trend of the size of shadow economy and the MFP index for each G7 country for the time period 1991-2018.

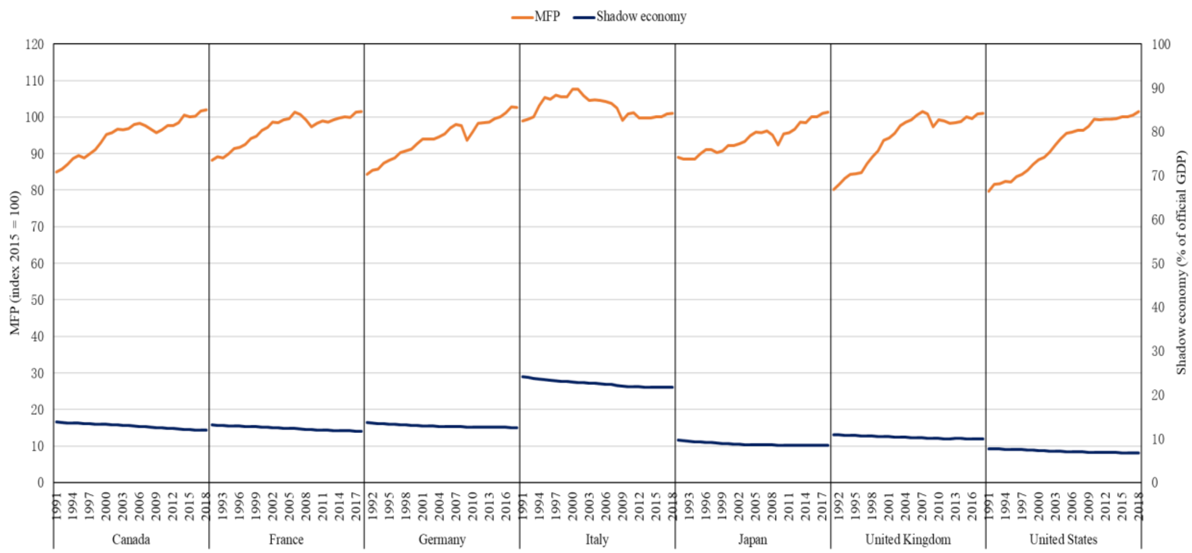

Fig. 2. Trend in size of shadow economy and MFP index of G7 countries, 1991-2018.

As convinced with the current situation of G7 countries, the authors are motivated to analyze the impacts of multifactor productivity, shadow economy and renewable energy consumption on HDI in 7 developed countries from 1991 to 2018 by using the Method of Moments Quantile regression (MMQR) developed by Machado and Santos Silva (2019). Quantile regression is an approach that provides a more comprehensive perspective on possible causal relationships between variables (Cade & Noon, 2003).

The contributions of this paper are as follows: First, this study is one of the rare studies that analyze the influences of the shadow economy and the MFP on HDI for developed countries, specifically in the G7 countries, from 1991 to 2018. Second, using the advanced panel quantile regression, the reliable outcomes show the heterogeneous impacts of shadow economy, renewable energy consumption and multifactor productivity

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on HDI in G7 across the quantile distribution. Besides, the study also analyzes the causal link between HDI and renewable energy consumption, shadow economy, and multifactor productivity in the G7 countries.

The rest of this study is organized as follows. Section 2 reviews previous studies after the introduction. Section 3 explains the empirical model and data. Section 4 presents the model, data and methodology of the current study. The conclusion and policy recommendations are presented in Section 5.

2. LITERATURE REVIEW

2.1. Economic growth, trade openness and human development

Numerous studies show that economic growth and human development are intrinsically linked and reinforce each other. Economic growth momentously impacts economic and human development (Anwar et al., 2021). So, the causal relationship between economic growth and human development becomes a mutually influential relationship (Elistia & Syahzuni, 2018).

Economic growth is often considered the first factor in evaluating a country's human development process because GDP per capita indicates the country's welfare (Elistia & Syahzuni, 2018). However, some notable studies have explored this relationship in different ways (Kaewnern et al., 2023), and the results of these studies have been inconsistent.

Most empirical studies show a positive impact between economic growth and human development (Acheampong et al., 2021; Hashemizadeh et al., 2022; Iqbal et al., 2019; Kaewnern et al., 2023; N. H. Khan et al., 2019; A. Pham et al., 2023; Wang et al., 2020). In contrast, some other studies suggested that economic development has a negative (Mustafa et al., 2017) or no impact on human development (Rivera, 2017; Wang et al., 2018).

Globalization entails that trade openness directly influences consumers' benefit in all nations (Gani, 2019). Similar to studies on the relationship between economic growth and HDI, the studies on the nexus between trade openness and human development also show inconsistent results. Several findings indicated that trade openness is positively linked to human development (Sinha & Sen, 2016; Sinha & Sengupta, 2019; Wang et al., 2020). Nonetheless, some studies continue to reach the contrary conclusion, arguing that trade openness has a detrimental effect on the human development (N. H. Khan et al., 2019; Wang et al., 2018).

2.2. Renewable energy consumption and human development

In recent years, the association between energy consumption and human development has been investigated by different studies in countries or groups of countries over different periods using different econometrics methodologies.

Pîrlogea's study (2012) is one of the first to investigate renewable energy's impact on human development. The results of this study revealed that renewable energy enhanced

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human development in specific nations in European Union countries from 1990 to 2013, including Ireland and Poland. The Pîrlogea's (2012) study emphasized the importance of managing energy consumption sustainably and promoting renewable energy to support human development.

The article of Sasmaz et al. (Sasmaz et al., 2020) conducted a study that examined the link between renewable energy consumption and the HDI in a sample of 28 countries belonging to the Organisation for Economic Cooperation and Development (OECD) countries from 1990 to 2017 by using the Westerlund and Edgerton panel cointegration test with structural breaks. Their research suggested that renewable energy significantly boosts human development in the long term. In addition, the causal analysis of this study also found a two-way causal relationship between renewable energy and human development. So, their study's findings suggested that investing in renewable energy projects can enhance human development in the OECD countries.

Likewise, Wang et al. (2021) investigated the impact of renewable energy consumption on human development in BRICS countries from 1990 to 2016 by employing Driscoll-Kraay standard errors estimates and Dumitrescu-Hurlin panel causality test, which can solve the issues of cross-sectional dependence. The authors found that renewable energy consumption positively affects HDI in the BRICS context. Besides, their findings considered that bidirectional causality linkage exists between renewable energy use and HDI. The authors argued that promoting the use of renewable energy can enhance human development.

Additionally, Kaewnern et al. (2023) relied on datasets of the highest-ranking ten nations in terms of HDI countries from 1996 to 2007 to demonstrate that economic growth increases the HDI by using advanced econometric methods (Feasible Generalized Least Square, the Driscoll Kraay standard errors, and Generalized Method of Moments). Hence, the study recommended that to advance human development and sustainability, the ten countries with the highest HDI should increase their expenditures on research and development and use renewable energy.

On the contrary, some other studies showed the opposite result. For instance, the study of Wang et al. (2018) showed that does not improve HDI in Pakistan from 1990 to 2014. In addition, Amer's (2020) study results, which explored the relationship between renewable energy and human development in 101 selected countries, showed that renewable energy consumption had an insignificant impact on HDI except for lower-middle-income countries from 1990 to 2015. As shown above, several studies have found evidence of the positive impact of renewable energy on human development. However, some studies still show the opposite result. Therefore, increasing renewable energy consumption increasingly closely affects improving human welfare.

Hence, it is still necessary to expand research on the influence of increased renewable energy consumption on human development. However, research on the link between renewable energy use and human development is still incomplete. (Wang et al., 2020).

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Conclusively, the impact of renewable energy consumption on HDI still needs to be further evaluated.

2.3. Shadow economy and human development

Globally, the hidden economy influences numerous aspects of the economy and society. The existence of the hidden economy is a concern shared by all societies, as it results in significant economic losses (Remeikienė et al., 2022).

The article of Remeikienė et al. (2022) explored the influence of the human development on informal economy in 11 EU transition economies from 1996 to 2015 by using the panel cointegration and the causality tests to analyze. Their article found that the HDI negatively impacts the the shadow economy. Besides, the article also found that HDI had a causal effect on the size of the shadow economy. The authors argued that policies that enhance human capital can help address the shadow economy problem because their study results showed that significant improvements in human development have reduced the size of the shadow economy.

Saafi et al. (2023) examined the link between pillars of sustainable development and the informal economy by applying both static and dynamic panel threshold models in 83 developed and developing nations from 1996 to 2017. For the global sample and developing countries, the shadow economy positively affects HDI when its size is below a certain threshold and a negative effect when it exceeds that threshold. However, for developed countries, their findings discovered that the shadow economy harmed HDI regardless of size. This implies that the shadow economy might undermine human development in developed countries by eroding tax revenues, weakening public institutions, and increasing inequality and corruption. The study suggested that a moderate shadow economy size can be associated with positive spillover effects on long-term growth as well as sustainable development.

The study conducted by Assidi et al. (2023) investigated the association between the informal economy and the three fundamental components of sustainable development: economic growth, human development, and environmental quality in 82 (developing and developed) nations from 1996 to 2017 by employing the first-differenced generalized method of moments panel threshold model. Their study analyzed whether the effects of the informal economy on three key pillars vary with the quality of governance. The study found that the impact of the shadow economy on human development is regime-specific, depending on the countries' level of governance quality. Hence, the authors suggested that improving the quality of governance can be an effective policy instrument for reducing shadow economy efforts and promoting economic, social, and environmental sustainability.

Additionally, some scholars have analyzed the effects of the shadow economy on level of development (Frank Wu & Schneider, 2019), environmental quality (Chu & Hoang, 2022), ecological footprint (Mawejje, 2023; Qayyum et al., 2021), poverty (Bolarinwa & Simatele, 2022) and foreign direct investment inflows (Bayar et al., 2020). These findings highlighted the importance of addressing the shadow economy for promoting human

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development, sustainable economic growth, and environmental protection. Nevertheless, the link between the underground economy and human development has not received enough research attention. (Saafi et al., 2023). Synthesizing related theories, the relationship between the underground economy and human development has not been fully researched. The impacts of the shadow economy on factors related to fundamental aspects of human development progress are complex and have long-term effects. Therefore, the existing body of knowledge requires more new, updated and additional research on this issue.

2.4. Multifactor productivity and human development

Although the determinants of productivity growth have been widely discussed theoretically and empirically, some gaps in the related literature still need further research attention (Elmawazini et al., 2018). Traditional total factor productivity fails to meet the needs of sustainable growth (Yue et al., 2019). The study by Liu et al. (M. Liu et al., 2023) examined how energy productivity, economic growth, and globalization affect CO2 emissions in six southern European countries (Cyprus, Greece, Italy, Malta, Portugal, and Spain) from 1990 to 2018. The authors found that energy productivity significantly affects CO2 emissions in the long run. Energy productivity reduces CO2 emissions. The authors argued that increasing investment in energy efficiency across all sectors of the economy will result in environmental advancements because improving energy efficiency can be a powerful tool to reduce C02 emissions.

Celik et al. (Celik et al., 2023) conducted a study to investigate the environmental implications of material domestic productivity, material intensity, and material footprint within the framework of the Environmental Kuznets Curve (EKC) hypothesis for G7 countries from 1970 to 2019. According to the findings of their article, material productivity mitigates environmental degradation in G7 countries. However, with particular emphasis on country-specific outcomes, material productivity exacerbated environmental degradation in Japan and Italy by increasing carbon dioxide and greenhouse gas emissions. Hence, the authors proposed policy recommendations for promoting responsible behavior among all economic actors.

Aydin et al. (Aydin et al., 2023) analyzed the effect of multifactor productivity on ecological footprint under the environmental Kuznets curve hypothesis, using data from 1990 to 2018 for G7 countries. According to country-based findings, their article found that multifactor productivity in Germany, Italy, and the United States has been associated with reducing environmental pollution. However, multifactor productivity was not statistically significant for the whole panel of G7 countries. The article of Dzeha et al. (2018) examined the link between total factor productivity, remittances, and human development in 21 African countries from 2010 to 2014.

The study found that total factor productivity has a negative effect on human development, while remittances have a positive effect in the context of these countries. However, their study found that the interaction effect of total factor productivity and

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remittances is positive, suggesting that countries that receive higher remittances can transform the negative impact of total factor productivity into a positive one.

In summary, multifactor productivity is one of the main factors determining economic growth (Aydin et al., 2023) and directly affects many aspects of the sustainable development process. In other words, multifactor productivity directly and profoundly affects human development factors. Nevertheless, there is a lack of empirical research examining the influence of multifactor productivity on human development. This is the existence of a theoretical gap that requires to be filled.

2.5. Literature gaps

Based on the existing body of literature and the current seam of discussion, a few gaps in the extant literature on human development have more to investigate: (i) There are not many studies on the link between the shadow economy, multifactor productivity and human development in the most advanced economies; (ii) The application of panel quantile regression combined with the linear model in studying this relationship is still limited; (iii) The influences of renewable energy, shadow economy and multifactor productivity on human development in G7 countries in 1991-2018 have not been analyzed. We establish the hypothesis of our study as follows:

Hypothesis 1

Renewable energy consumption and multifactor productivity might significantly and positively affect HDI for the G7 countries.

Hypothesis 2

The shadow economy significantly and negatively influences the HDI of the G7 countries.

Hypothesis 3

By utilising a blend of panel quantile regression and panel linear models, we propose that the influences of renewable energy, shadow economy, multifactor productivity, and other explanatory factors on the HDI of the G7 countries are complex and heterogeneous.

3. MODEL, DATA AND METHODOLOGY

3.1. Model specification

We aim to explore the impact of renewable energy consumption, shadow economy and multifactor productivity on human development for G7 countries. Based on the existing studies discussed in the theoretical framework review section and inspired by the study of Medina and Schneider (Medina & Schneider, 2019), the study of Sohag et al. (Sohag et al., 2021), and the recent study ...., we use the following empirical model:

$$HDI_{it} = f(GDP_{it}, RNE_{it}, MFP_{it}, SHA_{it}, TRO_{it}) \quad (1)$$

where *i* epitomizes the studied countries, *t* connotes the periods. In equation (1), HDI indicates the human development index, GDP refers to economic growth, RNE denotes

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renewable energy consumption, SHA is the shadow economy, MFP is multifactor productivity, and TRO shows trade openness.

In our empirical model, renewable energy consumption, multifactor productivity and shadow economy are the core explanatory variables. In order to reduce issues related to autocorrelation and heteroscedasticity and obtain accurate and consistent results, variables are transformed into natural logarithms to reduce dispersion and enhance data smoothness. The log-linear formulation of equation (1) therefore becomes:

$$\ln HDI_{it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln RNE_{it} + \beta_3 \ln MFP_{it} + \beta_4 \ln SHA + \beta_5 \ln TRO_{it} + \mu_{it} \quad (2)$$

where β_1, β_2, β_3, β_4, and β_5 are the parameters of *lnGDP, lnRNE, lnMFP, lnSHA* and *lnTRO*, respectively. Finally, the constant term is denoted by β_0 while the error terms are represented by μ_{it}.

3.2. Data

The data employed in this study was obtained from official international statistical sources. Utilising four data sources, our research applied to annual data covering 28 years from 1991 to 2018 for G7 countries. Specifically, the human development index data are acquired from the UNDP database. In addition, we obtain economic growth and multifactor productivity data from the OECD database.

Data for the shadow economy and trade openness are extracted from the World Bank database, while the data for renewable energy consumption are collected from the U.S. Energy Information Administration database. Based on the condition of data availability, a balanced panel consisting of seven countries is constructed. The description of variables and data sources is delineated in Table 1, while Table 2 and Fig. 3 present the descriptive statistics of variables and the correlation matrix of variables, respectively.

Table 1

The description of variables and data sources.

Variables	**Symbol**	**The description**	**Data sources**
Human development index	HDI	This variable represents the human development index measured by health, education and standard of living (index)	United Nations Development Programme (UNDP)
Economic growth	GDP	This variable represents the gross domestic product per capita (real GDP per capita)	OECD
Renewable energy consumption	RNE	This variable represents the renewable energy use (kWh per capita)	U.S. Energy Information Administration (EIA)
Multiple factor productivity	MFP	This variable represents the overall efficiency with which labour and capital inputs are used together in the production process (index 2015 = 100)	OECD

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Shadow economy	TRO	This variable represents the size of the informal sector estimated by the dynamic general equilibrium model (% of official GDP)	World Bank
Trade openness	TRO	This variable represents the share of the total of import and export in GDP (% of GDP)	World Development Indicators (WDI)

Table 2

Descriptive statistics of variables.

Variables	lnHDI	lnGDP	lnRNE	lnMFP	lnSHA	lnTRO
Mean	-0.12507	10.59869	8.328399	4.558299	2.642812	3.802111
Median	-0.11991	10.59681	8.1019	4.576951	2.676526	3.925093
Maximum	-0.05657	10.99554	10.47363	4.678423	3.366768	4.482261
Minimum	-0.24462	10.29081	6.33353	4.376999	2.095179	2.760662
Std. Dev.	0.039324	0.138249	1.045304	0.064865	0.339479	0.432702
Skewness	-0.72451	0.527341	0.621243	-0.72071	0.510844	-0.6789
Kurtosis	3.172418	3.406325	2.909785	2.870621	2.811352	2.480128
Jarque-Bera	17.38992	10.43253	12.67391	17.10471	8.815375	17.26333
Probability	0.000167	0.005428	0.00177	0.000193	0.012183	0.000178
Observations	196	196	196	196	196	196

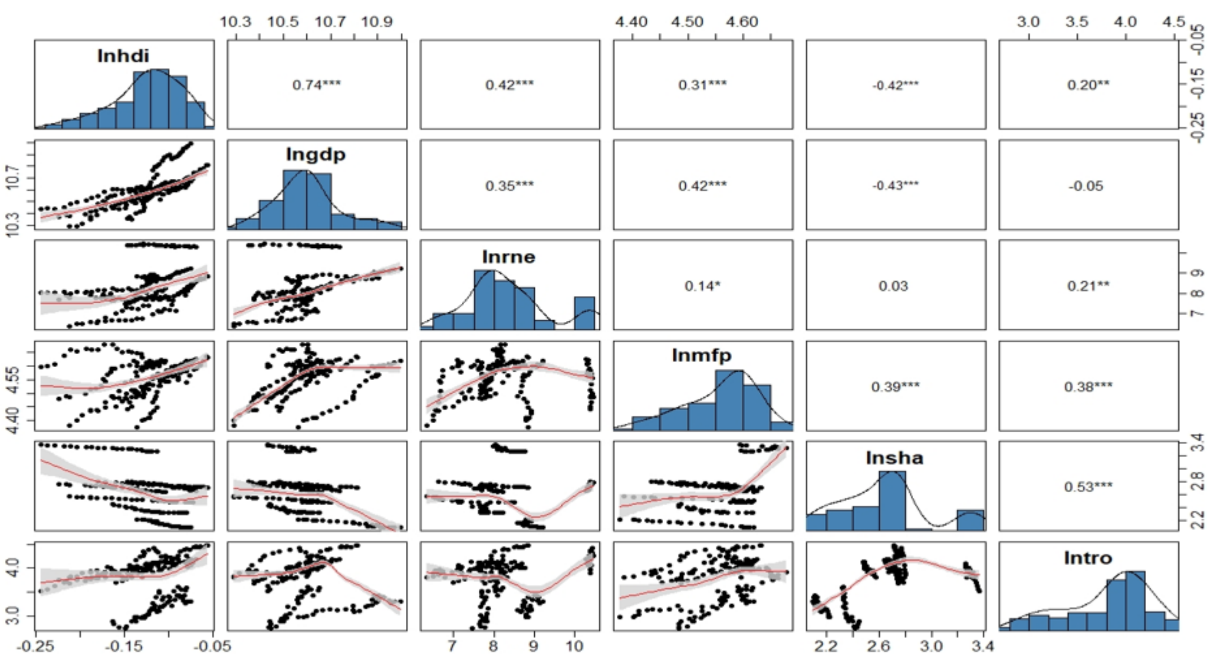

Fig 3: Scatter plot matrix, histogram, and correlation matrix of variables

3.3. Methodology

The econometric methodology approach of this paper follows the approach employed by (Erdoğan et al., 2022). Hence, we used a 6-step process. The Fig. 4 presents the flows of methodology

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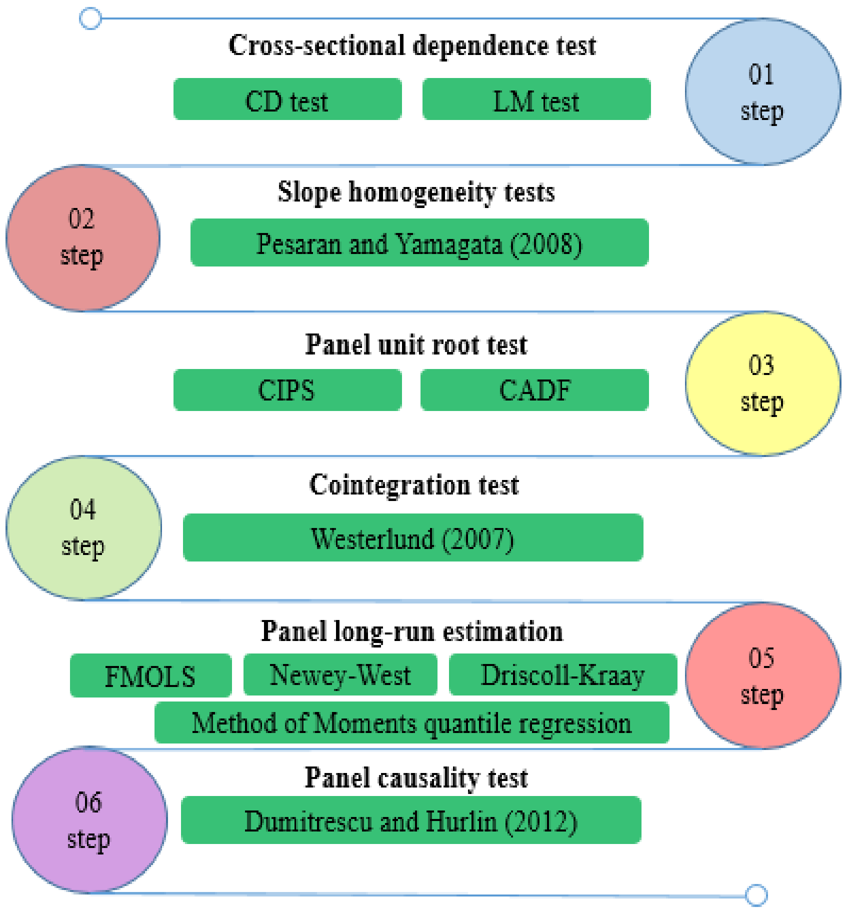

Fig 4: The road map of methodology

3.3.1. Cross-sectional dependence test

Cross-dependency is present when countries are interconnected at the global or regional level (E. A. A. A. Amer et al., 2022). Therefore, our study practices the Lagrange Multiplier (LM) test introduced by Breusch and Pagan (1980) and Pesaran CD test introduced by Pesaran (2004) to consider cross-sectional dependence in the data of the panel.

The basic equation of the LM test and CD test can be expressed as the following equations:

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij}^{2} \quad (3)$$

$$CD = \sqrt{\tfrac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij}\right) \quad (4)$$

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where N is the number of cross-sections and T is the time period, and $\hat{p}_{ij}$ presents the coefficients correlation of residuals. The null hypothesis for both tests assumes the absence of cross-sectional independence in the data, while the alternative hypothesis means the contrary.

3.3.2. Slope homogeneity test

The current research employ the slope homogeneity test proposed by Pesaran and Yamagata (2008), because doing the slope homogeneity test is essential before examining any relationship involving the equation (Cergibozan, 2022; Jin, 2022). The slope homogeneity test, as proposed by Swamy (1970), was designed to detect cross-sectional heteroscedasticity.

Nevertheless, the Swamy (1970) tests are valid for panel data models where the number of cross-sectional units is small relative to the number of time periods. Pesaran and Yamagata (2008) established two types of test statistics to examine the hypotheses depending on the sample size, as the following equation:

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}\right) \quad (5)$$

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - E(\tilde{Z}_{iT})}{\sqrt{var(\tilde{Z}_{iT})}}\right) \quad (6)$$

in which $\tilde{\Delta}$ is the standard dispersion test statistic, and $\tilde{\Delta}_{adj}$ is the following adjusted test, $\tilde{S}$ reflects the adjusted test, $E(\tilde{Z}_{iT}) = k$, k is independent variables, and $var(\tilde{Z}_{iT}) = 2k(T-k-1)/(T+1)$. The following modified test is applied when the samples studied are small.

3.3.3. Panel unit root test

Examining the stationary properties of the variables described is necessary to avoid leading to biased and misleading outcomes. However, the efficacy of the first-generation of the unit root test (Dickey & Fuller, 1979; Im et al., 2003; Levin et al., 2002) is compromised when cross-sectional dependence issues for variables are present.

Hence, this study employs second-generation unit root tests, namely the cross-sectional augmented IPS (CIPS) and the cross-sectional augmented Dickey-Fuller (CADF) tests proposed by Pesaran (2007). These tests can address the problem of cross-sectional dependence when examining the order of unit roots in the variables under analysis. The regression equation of the CADF test can be expressed as follows:

$$\Delta Y_{it} = \beta_i + a_i Y_{i,t-1} + b_i \bar{Y}_{t-1} + c_i \Delta \bar{Y}_t + \varepsilon_{it} \quad (7)$$

where Δ is the first difference estimator, Y_{it} denotes the analysed panel variable for individual i at time t, β_i is the individual constant ,a_i, b_j, c_i indicate the coefficients, $\bar{Y}_t$

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indicates of all cross-sectional observations at time t, $\bar{Y}_{t-1}$ is the first-order lag term of $\bar{Y}_{it}$ and ε_{it} presents the residual.

The CIPS statistic, which is calculated by taking a simple average of the former, as the following equation:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (8)$$

3.3.4. Panel bootstrap cointegration test

The cointegration test is an essential basic procedure before long-run estimation in order to identify the presence of cointegration among the variables under investigation. The first-generation cointegration tests like the Johansen (1990), Kao (1999), and Pedroni (2001) cointegration tests ignore the cross-section dependence issue, and this leads to the creation of misleading results regarding the long-run cointegration of variables (Habiba et al., 2022). Hence, after testing for stationarity, the Westerlund (2007) cointegration test was applied to investigate the cointegration of variables.

This methodology improves the computational precision of estimations by minimising the anomalies linked to the asymptotic normal distribution, thereby addressing the the presence of cross-sectional dependence more effectively (Danish, 2021; Usman et al., 2023).

This technique is based on four statistics, including the two mean-group tests (Gt and Ga) and two-panel test statistics (Pt and Pa). One notable benefit of this test is its ability to be iteratively applied in the bootstrapping process through the utilization of a sieve-sampling strategy (Jahanger et al., 2023).

3.3.5. Long run estimators

For empirical estimation, the study uses the fully modified ordinary least squares (FMOLS), the Newey-West standard errors, and the Driscoll-Kraay (1998) standard errors technique for investigating the impacts of RNE, MFP, SHA, GDP and TRO on HDI. The present study applies the Newey-West standard error regression technique because of its ability to address the issues of autocorrelation and heteroscedasticity (Bottomley et al., 2023).

Besides, the FMOLS is an appropriate method for solving the problem related to the existence of endogeneity between variables (Shahbaz et al., 2022). Nevertheless, cross-sectional dependency renders classic approaches like FMOLS incorrect or unreliable (Pedroni, 2001). Therefore, to obtain accurate results by overcoming the problem of cross-sectional dependence, our research uses the Driscoll-Kraay (1998) standard error method.

Moreover, our study extends the long-run analysis by applying the MMQR of Machado and Santos Silva (2019), which can provide more information about the relationship between regressors. This regression technique can investigate the heterogeneous influences of explanatory variables on HDI in G7 at different quantiles.

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MMQR has superiority over traditional conditional mean methods because it has advanced features, such as: (i) Offering further insights into the impacts of independent variables on the whole conditional distribution of the dependent variable is the essential characteristic of the MMQR (Erdoğan et al., 2022); (ii) The MMQR possesses the capacity to tackle the challenges posed by endogeneity effectively (E. B. Ali et al., 2024); The MMQR can accommodate the covariance impact in the overall distribution (Chien et al., 2023) (iii).

The following equation (9) is used to estimate conditional quantiles $Q_Y(\tau|X_{it})$

$$Y_{it} = a_i + X_{it}^{'}\beta + (\delta_i + Z_{it}^{'}\gamma)U_{it} \qquad (9)$$

where $\Pr\{\delta i + Z_{it}^{'}\gamma > 0\} = 1$ is the probability, and parameters $(\alpha, \beta', \delta, \gamma')$' are be assessed. $(\alpha_i,\ \delta_i)$, i = 1, …, n identifies a precise fixed effect. Moreover, Z designates the k-vector of components X, which are distinguishable alterations with element j as follows:

$$Z_j = Z_j(X), j = 1, 2, 3 \ldots k \qquad (10)$$

X_{it} is distributed identically and independently for fixed *(i)* and time *(t)*, which is orthogonal *(i)* and time *(t)*. U_{it} is distributed identically and independently for individuals (*i*) through time (*t*).

Model (9) can be formulated in the following manner:

$$Q_y(\tau \mid X_{it}) = (a_i + \delta_i q(\tau)) + X_{it}^{'}\beta + Z_{it}^{'}\gamma q(\tau) \qquad (11)$$

where $Q_y(\tau \mid X_{it})$ signifies the quantile distribution of Y_{it}, while $X_{it}^{'}$ covers independent vector parameters; $a_i(\tau) \equiv a_i + \delta_i q(\tau)$ shows the distributional effect at quantile τ.

3.3.6. Panel causality test

Lastly, the study used a modern second-generation causality test for panel data proposed by Dumitrescu and Hurlin (2012) in order to investigate the causal association between variables. The information collected via this test has significance in formulating appropriate policy recommendations (Çeştepe et al., 2022).

One notable benefit of employing this test is its applicability in situations involving heterogeneity and cross-sectional dependency (Akram et al., 2021). Furthermore, this test is suitable for analysing datasets with small *T* and *N* dimensions (Cergibozan, 2022). Moreover, the test can also be employed for panels that are not balanced.

Hence, by employing this test, greater accuracy, rigorous, and robust findings can be obtained to confirm the causal connections between variables. Dumitrescu and Hurlin (2012) propose that the causal relationship between variables can be expressed in the model as:

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$$y_{it} = \alpha_i + \sum_{i=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{i=1}^{K} \beta_i^{(k)} x_{i,t-j} + \varepsilon_{it} \qquad (12)$$

where $\beta_i = (\beta_i^{(1)}, \ldots, \beta_i^{(K)})$, $\gamma_i^{(k)}$ defines lag parameter, α_i is individual constants, K illustrates lag length, while $\beta_i^{(k)}$ presents the slope coefficients.

4. EMPIRICAL RESULTS AND DISCUSSION

Interactions between economies can result in existing cross-sectional dependence in panel data regression. The omission of cross-sectional dependence in panel data analysis might lead to estimation findings that are both biased and inconsistent. The estimated results of the cross-sectional dependence test are presented in Table 3. The observing p-values imply that cross-sectional dependence exists among the variables.

Table 3

Results of cross-sectional dependence test.

	lnHDI	lnGDP	lnRNE	lnMFP	lnSHA	lnTRO
LM test	30.76* (0.077)	48.23*** (0.000)	35.09** (0.022)	56.16*** (0.000)	37.09** (0.016)	37.85** (0.013)
CD test	23.72*** (0.000)	21.15*** (0.000)	7.5*** (0.000)	15.09*** (0.000)	23.39*** (0.000)	15.85*** (0.000)

Note: p-values are put in parentheses. ***, ** and * designate statistical significance at the 1%, 5% and 10% levels, respectively.

The resulting outcomes may be biased if the slope coefficients exhibit true heterogeneity but are mistakenly considered homogeneous. Therefore, we performed the Pesaran and Yamagata (2008) slope homogeneity tests and revealed that the p-values of both tests (standard $\tilde{\Delta}$ and bias-adjusted delta $\tilde{\Delta}_{adj}$ tests) are statistically significant at the 1% level. Hence, the null hypothesis of slope heterogeneity tests is rejected, indicating that the slope coefficients are not homogeneous at a 1% significance level. As a consequence, the slope coefficients exhibit heterogeneity.

Table 4

Results of homogeneity of slope test.

Tests	$\tilde{\Delta}$	$\tilde{\Delta}_{adj}$
LM statistics	113.852*** (0.000)	15.995*** (0.000)

Note: p-values are put in parentheses. *** designates statistical significance at the 1% level.

The results of Pesaran (2007) panel unit root test are tabulated in Table 5. The results demonstrate that all variables are stationarity when analysed using the first difference series, as confirmed by the significant P-values and test statistics obtained from both the CADF and CIPS tests, which were developed by Pesaran (2007). Specifically, these variables are significant at 1% and 5%, level of significance. Besides, for the level series, none of the variables is stationary. The outcomes of the CADF and CIPS panel unit root tests suggest that all variables are stationary at the first difference.

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Table 5

Results of the CIPS and CADF unit root test of panel.				
Variables	**CIPS**		**CADF**	
	Level	**First difference**	**Level**	**First difference**
lnHDI	-2.346	-4.584***	-2.346	-4.584***
lnGDP	-2.292	-3.625***	-2.292	-3.625***
lnRNE	-1.475	-5.623***	-2.750	-6.081***
lnMFP	-2.549	-4.368***	-2.549	-4.386***
lnSHA	-1.483	-3.054**	-1.483	-3.054**
lnTRO	-2.448	-3.373***	-2.448	-3.373***
Note: *** and ** designate statistical significance at the 1% and 5% levels, respectively.				

The stationarity of the variables at first difference implies the subject of whether or not the variables are long-run cointegrated may be addressed. Additionally, the Westerlund's (2007) cointegration test is utilised when cross-sectional dependence is present, as it yields reliable and consistent results (H. Liu et al., 2023). Hence, our study uses Westerlund's (2007) bootstrap cointegration test to explore the long-run relationship among variables, and the results of the panel cointegration test (the group statistics and panel statistics) have been presented in Table 6. For G7 countries, two mean-group tests (G_t and G_a) and two-panel test (P_t and P_a) statistics are statistically significant. Consequently, we do not find sufficient evidence to reject the alternative hypothesis that there is long-term cointegration among the series.

Table 6

Result of the Westerlund cointegration test.				
Statistic	**Value**	**z-value**	**p-value**	**Robust p-value**
Gt	-2.876*	-0.639	0.262	0.1
Ga	-20.008***	-1.615	0.053	0
Pt	-7.578**	-1.202	0.115	0.05
Pa	21.183***	-3.133	0.001	0
Note: ***, ** and * designate statistical significance at the 1%, 5% and 10% levels, respectively.				

After performing various diagnostic tests, the study conducted long-run estimates. This study integrates three models to provide a complete examination of the interrelationship between GDP, RNE, MFP, SHA, TRO and HDI in G7 countries. Table 7 presents the results of long-run regression (FMOLS, Newey-West standard errors and Driscoll-Kraay standard errors estimators) for equation (2).

Table 7

Results of FMOLS, Newey-West and Driscoll-Kraay regressions.						
Variables	**FMOLS**		**Newey-West**		**Driscoll-Kraay**	
	Coefficient	**Prob.**	**Coefficient**	**Prob.**	**Coefficient**	**Prob.**
lnGDP	0.110***	0.000	0.110***	0.000	0.110***	0.000
lnRNE	0.007***	0.000	0.007***	0.000	0.007***	0.000
lnMFP	0.110***	0.000	0.109***	0.001	0.109***	0.002
lnSHA	-0.061***	0.000	-0.061***	0.000	-0.615***	0.000
lnTRO	0.035***	0.000	0.035***	0.000	0.035***	0.000
Constant	-1.831***	0.000	-1.823***	0.000	-1.822***	0.000
Note: *** designates statistical significance at the 1%.						

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Interestingly, Table 7 shows that the estimated coefficients of all explanatory variables are statistically significant at the 1% significance level. Table 7 also shows that the outcomes produced by the three estimation approaches are highly consistent. In interpreting the coefficients, a 1% increase in GDP is associated with a decrease in HDI by 0.110%.

Similarly, a 1% increase in RNE is associated with an increase in HDI by 0.007%, a 1% increase in MFP is associated with an increase in HDI by 0.110% (FMOLS) and by 0.109% (Newey-West, Driscoll-Kraay), a 1% increase in TRO is associated with an increase in HDI by 0.035%. However, a 1% increase in SHA is associated with a decrease in HDI by -0.061% (FMOLS, Newey-West) and by -0.615% (Driscoll-Kraay).

The results of three estimation methods imply that GDP, MFP and TRO positively affect HDI in G7 nations. In contrast, the tabulated results show a negative relationship between the SHA and HDI in the G7 countries.

We also use MMQR (Machado & Santos Silva, 2019) to make the results more robust and meet the study's objectives. The outcomes of MMQR are presented in Table 8. Meanwhile, the graphical representation of the coefficient values in Fig. 5 clearly illustrates the positive and negative impacts of explanatory factors across all quantiles.

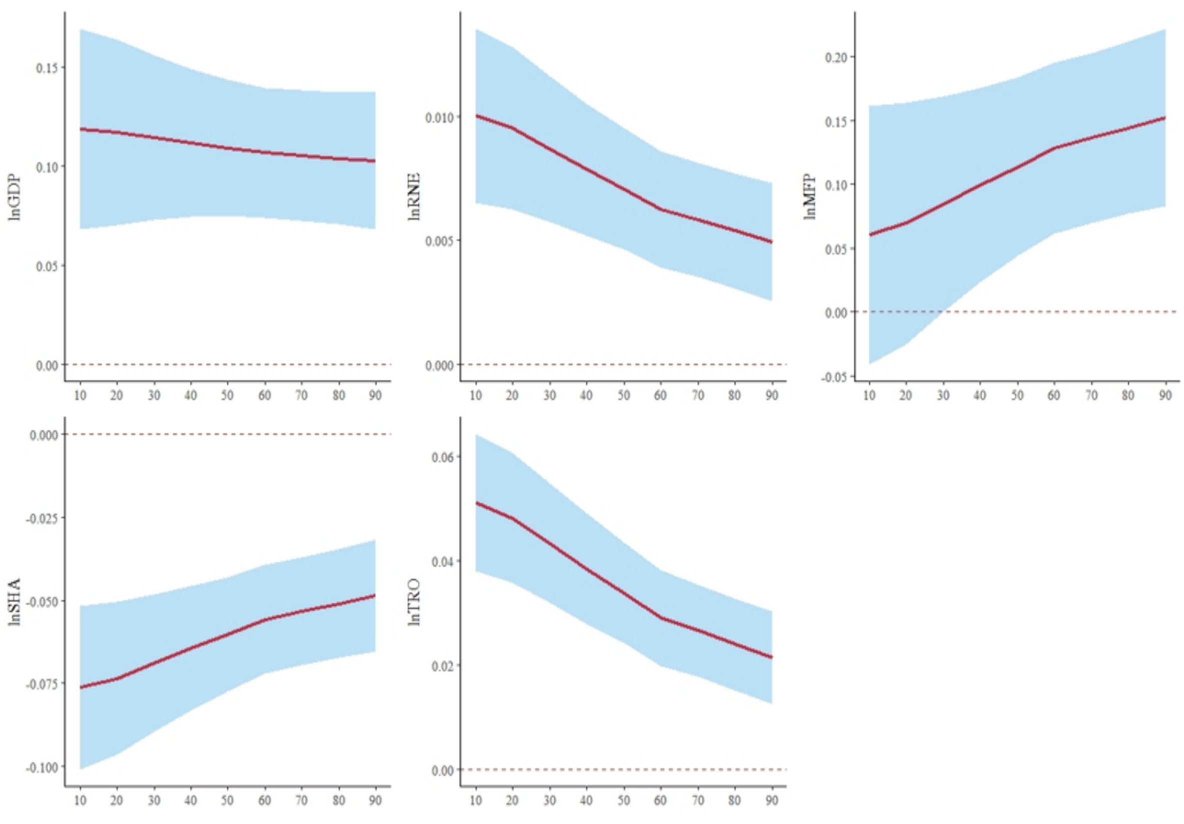

Fig 5: Changes in the coefficients of Method of Moments quantile regression

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Based on the results in Table 8, the findings of panel quantiles regression indicate the heterogeneous influences of explanatory factors on HDI. The results reflect the heterogeneous effects of MFP, RNE, SHA and other factors at different quantiles of HDI. More interestingly, all the estimated coefficients of GDP, RNE, SHA and TRO are statistically significant at the 1% level of significance across all quantiles. Specifically, the estimated coefficients of GDP range from 0.103 to 0.119, indicating that a 1% increase in GDP corresponds to a 0.103% - 0.119% rise in HDI.

Likewise, the estimated coefficients of RNE range from 0.01 to 0.0049, indicating that a 1% increase in GDP is associated with an increase in HDI by 0.01% - 0.0049%. Regarding the effect of MFP, the tabulated findings demonstrate that the estimated coefficient of MFP is positive and significant from the 30th to the highest (90th) quantile level. However, the impact of MFP on HDI is getting larger for higher quantiles. The calculated coefficients of MFP range from 0.0845 to 0.152, suggesting that a 1% increase in MFP corresponds to a 0.0845% - 0.152% rise in HDI. Additionally, the calculated coefficients for TRO range between 0.0215 and 0.0512, suggesting that a 1% rise in TRO corresponds to a 0.0215% - 0.0512% increase in HDI. On the contrary, the estimated coefficients of SHA range between -0.0763 and -0.0485, indicating that a 1% increase in SHA is associated with a decrease in HDI by 0.0763% - 0.0485%.

Table 8

Results of Method of Moments quantile regression.

Variables	Location	Scale	Quantiles								
			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
lnGDP	0.1101***	-0.0055	0.119***	0.117***	0.114***	0.112***	0.109***	0.107***	0.106***	0.104***	0.103***
	0	-0.524	0	0	0	0	0	0	0	0	0
lnRNE	0.0073***	-0.0017***	0.0100***	0.0095***	0.0086***	0.0078***	0.0070***	0.0062***	0.0058***	0.0053***	0.0049***
	0	-0.004	0	0	0	0	0	0	0	0	0
lnMFP	0.1092***	0.0317*	0.0602	0.0695	0.0845**	0.0996***	0.114***	0.129***	0.136***	0.144***	0.152***
	0	-0.069	-0.244	-149	-0.049	-0.01	-0.001	0	0	0	0
lnSHA	-0.0615***	0.0095**	-0.0763***	-0.0735***	-0.0690***	-0.0645***	-0.0602***	-0.0557***	-0.0534***	-0.0510***	-0.0485***
	0	-0.025	0	0	0	0	0	0	0	0	0
lnTRO	0.0354***	-0.0102***	0.0512***	0.0482***	0.0433***	0.0385***	0.0339***	0.0291***	0.0267***	0.0241***	0.0215***
	0	0	0	0	0	0	0	0	0	0	0
Constant	-1.824***	-0.0401	-1.762***	-1.773***	-1.792***	-1.812***	-1.829***	-1.848***	-1.858***	-1.868***	-1.878***
	0	-0.537	0	0	0	0	0	0	0	0	0

Note: p-values are put in parentheses. ***, ** and * designate statistical significance at the 1%, 5% and 10% levels, respectively.

Overall, based on a combined analysis of the findings shown in Table 7 (FMOLS, Newey-West, Driscoll-Kraay) and Table 8 (MMQR), from the impact of renewable energy consumption on HDI, the results revealed that renewable energy consumption has a positive influence on HDI in the G7 countries. Human development can benefit from renewable energy consumption in many ways. The investment in clean energy has had a notable increase of 40% since 2020 (IEA, 2023). Shift to the renewable energy can reduce poverty by providing employment opportunities (Dastgeer et al., 2023) and contributing to economic development (Magazzino et al., 2021). Additionally, using clean sources of energy not only helps mitigate climate change (H. Ali et al., 2023; Bilgili & Bağlıtaş, 2022) but also contributes to reducing air pollution (Danish et al., 2019) and improving public health (Mehmood, 2021). A study by Aydin et al. (2023) indicates that implementing renewable energy policy targets in G7 countries will yield favourable

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environmental outcomes. Similarly, the research of (Balsalobre-Lorente et al., 2023) advises that increasing renewable energy sources can facilitate sustainable development in G7 countries. The results of our study indicate that the enhancement of renewable energy use has the potential to expedite human development within G7 nations.

From the impact of MFP on HDI, the results revealed that has a significantly positive impact on HDI in the G7 countries. Growth in MFP is measured as a residual. Hence, MFP reflects the real increase in the nation's welfare (Filipenko, 2021). Krugman (1990) argued that a country's ability to raise the living standards of its people over time relies mostly on its ability to increase output per worker. In other words, increases in MFP will spur economic growth and raise living standards and well-being (OECD, 2023). The rapid MFP growth contributed to increases in the standard of living (Gullickson & Harper, 1987). Enhancing efficiency and productivity through adopting advanced technology can contribute to poverty reduction by generating additional employment possibilities, fostering wealth creation, and promoting human development (Wang et al., 2021). Additionally, the research of Aydin et al. (Aydin et al., 2023) found evidence that MFP reduces levels of environmental damage in some G7 members. The results of our empirical study also show MFP's positive impacts on human development. However, according to the MMQR results of our empirical study, the slope coefficient of MFP is insignificant from the 10th to the 20th quantile level, which indicates that not every increase in MFP impacts increasing HDI in G7 countries.

From the impact of SHA on HDI, our results revealed that SHA has a negative influence on HDI in the G7 countries. The research of Baklouti and Boujelbene (Baklouti & Boujelbene, 2019) found that SHA reduces economic growth in developed countries. Besides, the investigation of Chatti & Majeed (2023) demonstrated that SHA had harmful impacts on the environment in developed nations. The presence of a shadow economy is characterised by its operation outside the purview of environmental laws and regulations (Nguyen & Nguyen, 2023), enabling economic actors inside informal sectors to engage in economic activities with a higher propensity for pollution (Elgin & Oztunali, 2014). Furthermore, the study of Saafi et al. (2023) has revealed evidence that SHA negatively impacts not just HDI but also negatively affects the economic growth and environmental performance of advanced nations.

From the impact of GDP and TRO on HDI, our research shows that GDP and TRO drive the growth of HDI in G7 countries. Economic growth has always been considered the first factor in human development. Although, economic growth does not guarantee human development in all countries (Hou et al., 2015). However, economic development should lead to improved human development by expanding human choice (N. H. Khan et al., 2019). Besides, trade openness is also considered a factor that creates many benefits for human development (Sinha & Sengupta, 2019). Hashemizadeh et al. (2021) also found evidence that economic growth and globalization promote HDI within G7 countries.

Numerous studies conducted across various disciplines provide compelling evidence about the significance of the causal relationship between variables (Balsalobre-Lorente et al., 2022). Therefore, in the context of causality analysis, the present study employs

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the Dumitrescu and Hurlin (2012) examination to check the causality relationship. Table 9 provides the findings of the panel causality test. The bidirectional causal relationship is found between shadow economy and human development. Hence, changes in the size of the informal economy impact HDI and vice versa. Similarly, the results provide evidence of the two-way causal relationship between GDP and MFP, TRO and MFP, and TRO and SHA. Furthermore, the results reveal a flow of unidirectional causality relationship from HDI to GDP, from HDI to MFP, from HDI to TRO, from HDI to RNE, from MFP to SHA, from MFP to RNE, from GDP to TRO, from GDP to RNE, and from GDP to SHA. Fig. 6 depicts the causal connections among the variables under investigation.

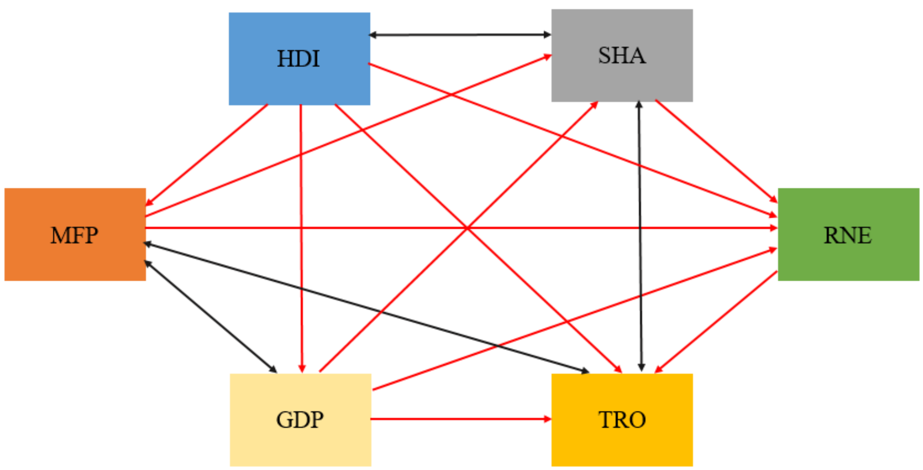

Fig 6: The direction of causality relations among variables

Table 9

Results of Dumitrescu-Hurlin panel causality test.

Variables	lnHDI	lnGDP	lnRNE	lnMFP	lnSHA	lnTRO
lnHDI	-	1.046 (0.942)	0.769 (0.607)	1.062 (0.963)	2.366** (0.041)	0.734 (0.569)
lnGDP	2.792*** (0.006)	-	0.915 (0.778)	3.086*** (0.001)	0.820 (0.665)	1.259 (0.787)
lnRNE	4.854*** (0.000)	3.151*** (0.001)	-	2.893*** (0.003)	5.141*** (0.000)	1.852 (0.223)
lnMFP	3.438*** (0.000)	2.843*** (0.005)	1.323 (0.709)	-	2.038 (0.129)	2.561** (0.018)
lnSHA	4.158*** (0.000)	7.280*** (0.000)	5.494 (0.000)	4.010*** (0.000)	-	2.539** (0.020)
lnTRO	8.796*** (0.000)	3.554*** (0.000)	2.207* (0.074)	4.830*** (0.000)	8.749*** (0.000)	-

Note: p-values are put in parentheses. ***, and ** designate statistical significance at the 1% and 5% levels, respectively.

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5. CONCLUSION

The process of recovering and redesigning economic systems in advanced economies to enhance human development and compatibility with the environment is facing hazardous issues. Rapid transitions to renewable energy sources are necessary for the mitigation of climate change (WEF, 2020). Hence, more research is needed on policies to enhance environmental sustainability, especially in the industrialized world, such as G7 economies (Qin et al., 2021).

Given this, we investigate the role of RNE, MFP, SHA, GDP and TRO in human development progress in the context of the G7 countries during the period spanning from 1991 to 2018. The results of our study indicate that MFP, GDP, TRO and renewable energy can serve as effective tools to enhance HDI, whereas SHA adversely affects HDI in the context of G7 countries. Furthermore, the panel causality test results provide a bidirectional causality between HDI and SHA and a unidirectional causality between HDI and other explanatory variables.

Renewable energy offers a more secure future because it drives economic growth, new jobs and poverty reduction. Besides, using renewable energy in the production process will help increase productivity in the long run through various macroeconomic channels (Sohag et al., 2021). Therefore, all policies aimed at renewable energy create conditions for human development. Although the size of the underground economy in G7 countries tends to decrease over time, and its negative impact on HDI also gradually decreases from low quantiles to high quantiles, the underground economy is still a significant challenge for G7 countries in the process of human development as well as achieving sustainable development goals. Production of goods and services is secretly concealed from public authorities in the underground economy (Schneider, 2016), which can negatively impact workers, economic development, social justice and the ecological environment. Policies to strengthen management using information technology and anti-tax evasion policies will have the ability to reduce the harmful effects of the underground economy. Increasing MFP is still an inevitable trend in all economies, and even finding ways to increase MFP is still fierce competition between countries. However, policies promoting MFP development must consider comparing economic efficiency with the environment and natural resources trade-off costs. And more importantly, human development must benefit from enhanced MFP.

In short, G7 countries should encourage improved MFP and clean energy consumption while reducing the size of the underground economy in their economies. G7 countries' policies can use tax and fiscal incentives to promote renewable energy adoption and environmentally friendly productivity innovation. Industries should not be encouraged to increase productivity at the expense of environmental safety. At the same time, the policies of G7 countries still need to focus on supporting innovations in energy conversion research and MFP enhancement, which will create conditions for these countries to reduce the harmful effects of environmental pollution and develop an effective green economy.

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