Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

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To cite this article: Quyen Doan Thuc, Khoa Dang Duong, Quynh Doan Huong, Nguyen Ho Viet Anh, Thanh Quang Ngo & Thanh Xuan Bui (2023) The role of ecological consequences of green energy in developed and developing economies, Economic Research-Ekonomska Istraživanja, 36:1, 906-929, DOI: 10.1080/1331677X.2022.2080744

To link to this article: https://doi.org/10.1080/1331677X.2022.2080744

Published online: 18 Jul 2022.

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2023, VOL. 36, NO. 1, 906–929
https://doi.org/10.1080/1331677X.2022.2080744

The role of ecological consequences of green energy in developed and developing economies

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ABSTRACT

Recently, green energy has been a significant factor in the technology changes that require researchers' emphasis. Thus, this study examines the impact of green energy such as renewable energy production, energy import and renewable energy consumption on the technological changes. The current article also investigates the role of economic factors (control variables) such as economic growth and population growth on the technological changes. The present research has selected ten developed and ten developing countries and extracted the data from 2008 to 2019. This article adopted fixed-effect model (FEM), robust standard error and generalized method of moments (GMM) to examine the association between the variables. The results indicated that green energy, such as renewable energy production and renewable energy consumption, along with economic factors such as economic growth, have a positive association with technological changes. The results also indicated that energy import and population growth have a negative association with technological changes. This article guides the regulators while developing effective policies regarding technological changes in the country.

ARTICLE HISTORY
Received 8 February 2022
Accepted 14 May 2022

KEYWORDS
Green energy; renewable energy production; energy import; renewable energy consumption; technological changes; economic growth

JEL CODES
N7; O3; K32

1. Introduction

The use of technology, which is the combination of machines and the related techniques, skills, methods, and processes, has an inevitable role in people's everyday lives. In this dynamic world, without technology, life is meaningless. As technology progresses, it makes both the social and economic spheres of life more convenient. Technology has become part of social and economic life. But, it is the critical factor

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for the survival of the economy in the quick phase world. The development of novel technologies is helpful in protecting the work environment, improving the health of human resources, improving productivity, increasing work efficiency, and making the economy better (Asongu & Odhiambo, 2020; Chien et al., 2022). The use of technology determines how the people and business organizations perform their functions as it is the technology that determines the change in the communication with everything around. The benefits of technology are higher than the expectations of individuals and economies. For a better, standardized economy and social life, attention is paid to new innovations in technology (Chien et al., 2021a; Chien et al., 2021b; Jokanović et al., 2017). In emerging countries, technology provides stronger infrastructure, better transportation, more productivity, and better sanitation, education, and health services. Because of the advances in technology, medium and small businesses increase and spread across countries. Technology innovation provides the power to organizations to spread their wings. The positive influences of technology on the environment, society, and economy bring revolution in the world and help reach heights that have never been thought of Chien et al. (2021c) and Freire (2019).

In economics, the technological change is the change in the technology, or, in other words, it is the improvement in the efficiency of a technological product like any mechanic devise, techniques, skills, or processes which brings an increase in output without any increase in inputs. In other words, it is the invention of or value addition to technology products, processes, or skills that must give a bigger reward for the application of the same quantity of inputs (Ehsanullah et al., 2021; Ngo & McCann, 2019). For instance, the computer is a technological product that has passed through technological change. Different technological changes have occurred to this product since the invention of its first model, the change that has increased computer efficiency. The technological products or processes go through technological changes in three stages of the invention (introduction of an entirely new item), innovation (put the item invented into use for the first time), and diffusion (the speed by which others adopt the invented item) (Huang et al., 2021a; Hwang & Shin, 2017). The change in the technological products, skills, techniques, and processes do have an impact on our economy in different manners. Technological change through the creation of products or processes adds positively to the features of technology; for instance, the telephone at the time of its invention is used for verbal communication with someone. After technological changes, the ways to communicate have increased like text, talk, or email (Glover et al., 2019; Huang et al., 2021b). The technological change increases the efficiency of the product and reduces cost; for example, the improvement in the manufacturing technology results in the increase in both quantity and quality of goods with the same input. The increased amount of goods and services with improved quality decreases the costs of manufacturing. The technological changes improve the work environment with improvement in the efficiency of labour force by reducing the use of efforts or energy and improving health (Huang et al., 2021c; Li et al., 2021; Zhu et al., 2018).

The main focus of our study is on technological changes and the impact of ecological consequences of renewable energy consumption, renewable energy production, and energy import along with economic growth and population growth on

technological changes. This study analyzes the influences of ecological consequences of renewable energy consumption, renewable energy production, and energy import, economic growth, and population growth on technological changes in ten developing and ten developed economies. This study addresses ten developed economies like Norway, Australia, Switzerland, Netherlands, USA, Germany, New Japan, Canada, Singapore, and South Korea and ten developing countries like Russia, China, Pakistan, Indonesia, Vietnam, Iraq, Argentina, South Africa, Guinea, and Saudi Arabia. In these developed and developing countries, technology is the key driver of the economic growth of cities, regions, and the overall country. It is technological development in these countries which accelerate the performance of economic activities in different economic sectors like agriculture, manufacturing, transportation, health, food, and education sectors as evidenced by Bamati and Raoofi (2020), in some developed countries as mentioned above. The technological adoption and development bring improvement in manufacturing processes, saves time and costs, makes efficient use of the resource, and gives high productivity with better quality as analysed by Omwoma et al. (2017) and Liu et al. (2021a), in some fast-emerging economies. The study by Liu et al. (2021b) and Shaw et al. (2020) states that the use of technology and consistent development in technology is an effective source of information and communication in Japan, China, and Korea.

All the selected developed and developing economies are engaged in the technology evolution, trade, and adoption but in different proportions. Japan is at the top of the list of countries with technological advancements. South Korea is the 2nd largest economy in the world for technological development and expertise (Matyushok et al., 2021; Yousaf et al., 2021). LG, Hyundai, and Samsung are all headquartered in South Korea. Its modest drop is due to a decrease in production, but this is not a cause for concern. Germany is one of the advanced technologically advanced countries. Germany is the 3rd best country in the world with 5th rank in technological experts. Germany is famed for its engineering, with Volkswagen, Siemens, and other companies based there. Germany is known for its engineering schools, which produce some of the top engineers in the world. Germany has also emerged as a global leader in technology used in medical, military, and infrastructure. Norway is the hub of green technology ranging from renewable energy industry manufacturing, transportation, and food production. For instance, Norway sells 39% of electric cars across the world (Kumar & Samadder, 2017; Moslehpour et al., 2022a). Australia is also famous for changes in technology adoption. Australian enterprises focus on 10 top technologies like opportunistic AI extension, cloud-centric infrastructure and applications, edge acceleration, hybrid by design, digital resiliency, automation, rebuilt relationships with providers, investment in people, the circular economy, and coping with technical debt. China is the most populous country focusing on green technology and is on the 3rd among the countries famed for technology expertise. Russia is the 6th advanced country for its engagement in technical expertise (Moslehpour et al., 2022b; Sun et al., 2021).

The environmental problems like air, water, or land pollution, global warming, rise in the level of the ocean, lack in the amount of oxygen in the air, and spreading of any chemicals etc. are almost in every country because of the rise in the population

and their social and economic activities. There are several factors that may cause or remove pollution spreading, like the choice of energy resources for undertaking different activities. Moreover, the modern market is highly competitive, and this is the age of digital technology. In order to compete against rival businesses, it is compulsory to bring improvement in technologies or relevant techniques, processes, and skills.

Our study put the attention of the readers towards this side by explaining how positive changes can be made in the technologies or relevant techniques, processes. The objective of the present study is to explore the influences of green energy such as renewable energy production, renewable energy consumption, and energy import along with economic growth and population growth on the technological changes. The present study has great theoretical significance for removing many literary gaps with subtle additions. First, in most of the studies green energy has been discussed as a whole without elaborating the renewable energy production, renewable energy consumption, and energy import while analysing technological changes. Like, Zecca and Nicolli (2021), has addressed the green energy as a single complete term while analysing the technological changes in the economy. The present study, which analyzes the ecological consequences of renewable energy production, renewable energy consumption, and energy import as three dimensions of green energy to determine the technological changes, is a significant addition to the literature. Second, in the prior research, mostly renewable energy consumption has been discussed for their impacts on the technological changes. Very few studies have paid attention to renewable energy production for the technological changes. The current study removes this literary gap with simultaneous analysis of renewable energy production and renewable energy consumption impacts technological changes. Third, this is for the first time that the nexus among green energy such as renewable energy production, renewable energy consumption, and energy import along with economic growth and population growth and the technological changes in both developing and developed countries.In the previous studies, only one or two countries which are either developing or developed ones are taken as the centre of analysis for the impacts of ecological consequences of green energy such as renewable energy production, renewable energy consumption, and energy import along with economic growth and population growth on the technological changes. The empirical significance of the study much wider as it is applicable to large number of countries covering both the developed and developing countries. The developed countries which themselves are proficient in making technological inventions or exports for high technologies and concerned equipment and developing countries which are making efforts to bring technological changes. This study has great significance to the economists how they can promote innovative technologies within the economy through encouraging green energy such as renewable energy production, renewable energy consumption, and energy import. This study is significant to the environmental regulators for guidance to them that they with the adoption of green energy, ecological friendly technologies can be promoted in the market and environment thus can be saved.

This article is structured as follows. The 2nd part briefly discusses the literary views about the impact of ecological consequences of green energy such as renewable

energy production, renewable energy consumption, and energy import, economic growth, and population growth on the technological changes. The third part describes the procedure to collect data and its analysis for the study results. These results are compared to and match with the previous studies. The discussion of the study results is followed by appropriate implications, conclusions, and future recommendations.

2. Literature review

Technological change, which is the change in the technological products, skills, techniques, and processes, is critical to economic progress (Gadeikiene & Svarcaite, 2021; Rastogi et al., 2018). Technological change improves the efficiency of technology. This improved efficiency may result in the acquisition of quality information, better communication, increase in the number of products and improves the quality of products (the reliability, design improvement, health protection, and durability of products) (Ma et al., 2021; Moslehpour et al., 2021). The positive changes in technology lead businesses towards success as people want innovation and newness. The change in the technologies can be made for several reasons like ecological consequences of green energy such as renewable energy production, renewable energy consumption, and energy import (Li et al., 2021; Othman et al., 2020). The environmental consequences of green energy bring improvement in the efficiency of the technologies, techniques, skills, and processes in this regard (Hassan et al., 2022; Sadiq et al., 2021a; Sadiq et al., 2021c). Similarly, economic growth and population growth also affect technological changes. The influences of ecological consequences of green energy such as renewable energy production, renewable energy consumption, and energy import, economic growth, and population growth on the technological changes have dominant attention in the past literature with the help of which the study hypotheses are proposed. Green energy is very important from an environmental perspective because it replaces the negative environmental impact of fossil fuels with ecological-friendly alternatives (Langkau & Espinoza, 2018; Piligrimienė et al., 2021; Sadiq et al., 2021b). As green energy is derived from natural resources, it is clean and replenishing. They produce no greenhouse gas or reduce the emission of pollutants, and these are readily available.

The production of energy is critical to society and the economy, as it assures the undertaking of different domestic and commercial activities, but it may leave impacts on the environment (Ali et al., 2018; Tan et al., 2021). The nature of the ecological consequences of energy production is determined by the nature of energy produced like renewable energy (wind power, hydropower, solar power, geothermal power, and non-renewable energy. The production of renewable energy like wind power, hydropower, solar power, geothermal power, biomass, and biofuel brings positive technological changes as it does not cause the emission of greenhouse gas, CO2, SO2, and wastes (Pursiheimo et al., 2019; Xiang et al., 2021). The literary workout of Przychodzen and Przychodzen (2020) and Xueying et al. (2021) analyzes the impact of renewable energy production on the environment and technological changes in transition economies. An extensive data were acquired from 27 transition economies for the period of 1990–2014 for the analysis of the impacts of renewable energy

production on environmental quality and the technological changes. According to the arguments of Przychodzen and Przychodzen (2020) and Zhao et al. (2021) the methods to produce renewable energy such as wind power, hydropower, geothermal power, solar power, biomass, and biofuel do not release any harmful gas or chemicals and do not leave any contaminating wastes within the country. That is why the individuals or organizations which have environmental concerns change the technology and the techniques to produce and consume energy. In Lyytimäki's (2018) study on renewable energy production, renewable energy consumption, environmental quality, and technological changes. The study compares the production of renewable energy resources like biomass and solar power etc. with the production of non-renewable energy resources like fossil fuels and nuclear power and states that, unlike non-renewable energy, the production of renewable energy does not emit greenhouse gas but absorbs the heat and carbon dioxide from the air, and excessive water from the earth. When the country has a clean and healthy environment, the economy has skilled and active human resources who have the ability to bring improvement in the applied technology or introduce entirely new technology or technological processes. Abdin and Zio (2018) argue that wind power, hydropower, geothermal power, solar power, biomass, and biofuel are examples of green energy techniques or processes that do not cause pollutants to spread throughout the country. As a result, firms that require energy to meet their business needs alter the pattern of energy production and consumption, similar to how applicable techniques or technologies are altered. Based on the above discussions, we can develop the following hypothesis:

H1: Renewable energy production has a positive relation to technological changes.

Energy resources are used to operate different technologies in all business departments like accountancy, information management, communication network, production, and logistics. The choice of energy resources for business operation affects the environmental performance of the firms, the quality of technology, techniques, processes, and human resources skills to operate the relevant technology or machinery (Bilan et al., 2020; Jia et al., 2018). The consumption of renewable energy resources affects technological development in different manners like; consumption of renewable requires specific technology which does not rely on non-renewable energy like fossil fuels, it ensures the skilled and active labour force who can carry technologies efficiently, adds value to the technology, or invent new techniques or technology, and the use of renewable energy reduces the costs or increases profits which are used to bring technological alteration (Flores & Chang, 2019; Gielen et al., 2019). A study by Alvarez-Herranz et al. (2017) integrates the relationship between energy innovation, renewable energy consumption, and technology change. This study collects empirical data for the association among energy innovation, renewable energy consumption and low-carbon technology from 17 OECD countries for the period of 1990–1912. The study implies that innovation in getting the energy from natural resources ensures the availability of renewable energy, which can be renewed, and do not emit harmful substances. The use of renewable energy for business operations encourages technology that emits less amount of harmful gases like CO2 emission. A study of Overland (2019) analyzes the nexus between renewable energy consumption, environmental performance, and technological changes. The study posits that the

organizations which use renewable energy resources for operating different business operations, production, and logistics, provide a clean and healthy environment to the labour force. The healthy labour force work actively. They can focus on the technology, techniques, or technological processes applied and try to improve their efficiency with some changes in their technology products, processes, or skills to use the technology. The literary investigation by García-Olivares et al. (2018) reveals that when renewable energy is used to carry business operations, the quality of resources is better, the effectiveness of business operations is achieved, the quality of products and services improves, wastes are reduced, and there is large marketing. The reduction of costs and increased profits enhance the financial resources of the firms, which they can use to make alterations in the technology. The afore-mentioned literary arguments about the renewable energy consumption and technological changes lead to the following hypothesis:

H2: Renewable energy consumption has a positive relation to technological changes.

The facility to procure energy from foreign countries brings changes in the domestic environment, social and economic progress. The import of green energy or renewable energy like wind power, hydropower, geothermal power, solar power, biomass, and biofuel ensures energy supplies within the country, develops consistency in the economic activities, improves productivity, and reduces the use of fossil fuels (Gutiérrez & Teshima, 2018; Heinrich et al., 2020). The import of renewable energy improves the environmental quality without reducing the economic activities and brings positive changes in the technologies or technological processes, techniques, and skills. An empirical investigation was made by Huang et al. (2017) to explore the influences of ecological impacts of green energy import and technological changes within the domestic organizations. The study implies that the quality of the inland environment, the work environment inside domestic companies, and the health of living beings are all affected by the import of energy resources to meet domestic energy needs. As a result, the type of technology and techniques utilized in the country for economic operations is determined by the energy import facility. The study conducted by Dlalisa and Govender (2020) and Shao et al. (2019) investigated the energy import, energy-saving performance, and technological changes in the presence of rebound effect. The state-space model with time-varying parameters, IPAT identity and the Solow residual approach for the analysis of the relationship among the energy import, energy-saving performance, and technological changes with a rebound effect in Shanghai, the city of China, for the period of 1991–2016. The study reveals that the study highlights that there is a reciprocal relationship between energy import and technological progress. The increase in technological progress enhances the need for energy within the country, having disturbed the achievement of the target of energy-saving policies. However, the facility to import green energy improves the quality of the atmosphere, natural resources, and living beings' health within the country. This reduces the overall costs and improves profitability. Thus, it brings positive technological changes within the country. On the basis of above given literary views about the energy import and technological changes, we can hypothesize:

H3: Energy import has a positive relation to technological changes.

Besides the ecological consequences of green energy such as renewable energy production, renewable energy consumption, and energy import, economic growth and population growth also have an impact on technological changes. Agustina et al. (2019) present their opinion on the role of high economic growth rate in developing technologies and relevant techniques, processes, and skills. The study implies that when the country makes fast economic growth, the financial position of the individuals, business firms, ad government become strong, and they have the capacity to make an investment in constructive or productive technologies and procedures in this regard. A study conducted by Han and Lee (2020) highlights that when the country is making rapid economic progress, agriculture, manufacture of goods, delivery of services, and transportation are all expanding their operations. All these operations will necessitate the use of new technology, innovative procedures, and enhanced techniques. The increased financial resources make them successful in bringing improvement in the efficiency of existing technologies and technological skills or inventing some new technology or techniques. Based on the above discussions, we can develop the following hypothesis:

H4: Economic growth has a positive relation to technological changes.

Literary research by Mullan and Haqq-Misra (2019), investigates the association between population growth, global warming, and technological changes. The study posits that the increase in the population has caused carbon emission in large amounts, which continue to add to global warming by nature or through an increase in human activities especially use energy. Over time technology goes through changes for the de-carbonization of energy production and consumption. For example, old technology based on the utilization of coal transformed into technology utilizing oil or natural gas. Another example is the invention of energy-efficient technologies. Berger (2019) and Koloba (2020), viewed that the fundamental and supplementary requirements of life are in vast supply in countries with strong population growth rates. As a result of the increasing demand for goods and services, economic activity and employment have increased. In order to satisfy the growing demands, technology is being used, new technologies are being invented, and existing technologies are being improved. Thus, the increase in the population growth rate causes several technological alterations. On the basis of the above-mentioned literature review about the population growth and technological changes, we can hypothesize:

H5: Population growth has a positive relation to technological changes.

The current article has used the theory of change for the development of the study framework. The theory of change describes the adoption of the best resources, management, and evaluation in the companies (Jelača et al., 2020; Kikulwe & Asindu, 2020; Reinholz & Andrews, 2020). The current article also examines the best resources, such as green energy's role in the technology changes that are adopted for the companies' success. Many of the past studies also used the theory of change, such as Douthwaite and Hoffecker (2017), who also examined the impact of the different resources on the adoption of agricultural innovation. In addition, a study by Gudanowska et al., (2020) and Vlaev and Dolan (2015) also used the theory of change to predict the companies' resource impact of technology and behavioural change.

Table 1. Measurements of variables.

S#	Variables	Measurements
01	Technology changes	High technology export (% of manufactured exports)
02	Green energy	Renewable electricity production (% of total electricity production)
		Renewable energy consumption (% of total energy consumption)
		Energy import (% of energy use)
03	Economic factors	GDP growth (annual %)
		Population growth (annual %)

Source: WDI.

3. Research methods

The researchers examine the impact of green energy on the technological changes in developing and developed countries and also investigate the role of economic factors on the technological changes in developing and developed countries. The present study has used green energy as the independent variable. In contrast, economic factors have been taken as the control variable, and technology changes have been used as the predictive variable in the study. The researchers have selected the ten most GDP generated developed such as Norway, Australia, Switzerland, Netherlands, USA, Germany, Brazil, Canada, Singapore, and Belgium and ten most GDP per capita generated developing countries such as China, India, Japan, Indonesia, Turkey, South Korea, Saudi Arabia, Iran, Thailand and Taiwan extracted the data from 2008 to 2019. The present study has used secondary sources like WDI and extracted the secondary data from the mentioned source. In addition, the article also executed the robust standard error to test the associations among understudy constructs because the data are cross-sectional dominant. Moreover, the article also used the FEM to examine the association between the variables. The equation of the present study is mentioned below:

$$HTE_{it} = \alpha_0 + \beta_1 REP_{it} + \beta_2 REC_{it} + \beta_3 EI_{it} + \beta_4 EG_{it} + \beta_5 PG_{it} + e_{it} \quad (1)$$

where HTE = high technology export; i = country; t = time period; REP = renewable energy production; REC = renewable energy consumption; EI = energy import; EG = economic growth; and PG = population growth. The current article has used the technology changes as the predictive variable and measured as the high technology export (% of manufactured exports). In addition, the current study has also used green energy as the predictor and measured as the renewable electricity production (% of total electricity production), energy import (% of energy use) and renewable energy consumption (% of total energy consumption). Finally, the current study also used the economic factors as the control variables and measured as GDP growth (annual %) and population growth (annual %). These variables with measurement have been mentioned in Table 1.

The current article has executed the descriptive statistics that show the variables minimum and maximum values and the total observations. In addition, it also shows the mean and standard deviation of the understudy constructs. Moreover, the current article also shows the correlation among the understudy constructs using the matrix of correlation that provides just direction, not the significance. Additionally, the current study also checks the multicollinearity using variance inflation factor (VIF) that

indicated the correlation among the predictors. If the values of VIF are not higher than five, then the multicollinearity assumption proved as valid. The equations for VIF are mentioned below:

$$R^2YY_{it} = \alpha_0 + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + e_{it} \quad (2)$$

$$j = R_Y^2,\ R_{X1}^2,\ R_{X2,}^2\ R_{X3,}^2\ R_{X4,}^2 R_{X5}^2 \quad (3)$$

$$Tolrance = 1 - R_j^2\ \ VIF = \frac{1}{Tolerance} \quad (4)$$

In addition, the article also executed the robust standard error to test the associations among understudy constructs because the data are cross-sectional dominant (countries are more than years). Moreover, a robust standard error has been used because it adjusts the "model's heterogeneity issues" that generally exist. This model is also suitable when the data have heteroscedasticity and auto-correlation issues. In addition, past studies such as Chin et al., (2021) and Kahan (2014) investigated that non-robust standard errors estimates can be highly misleading, and in this case, robust standard errors perform well. The equation for robust standard error estimation is mentioned below:

$$HTE_{it} = \beta_1 REP_{it} + \beta_2 REC_{it} + \beta_3 EI_{it} + \beta_4 EG_{it} + \beta_5 PG_{it} + \varepsilon_{it} \quad (5)$$

The study also executed the Hausman test to select the suitable regression model among FEM and random model. If the Hausman test probability value is not less than 0.05, then the random model is appropriate, but if the probability value is less than 0.05, then FEM is suitable. The equation for the Hausman test is mentioned as under:

$$H = (b_1 - b_0)\ (Var\ (b_0) - Var\ (b_1))\ (b_1 - b_0) \quad (6)$$

In above equation, "H" stands for Hausman test, b_0 shows the null hypotheses about the random effect is appropriate, while b_1 shows the alternative hypotheses about the FEM is appropriate. In addition, the current study has used the FEM because in this model, model parameters are fixed, and it also allows to control for all "time-invariant" omitted constructs. This model is particularly essential when the constructs are difficult to observe. In FEM, the researchers can estimate the number of additional parameters. Thus, the equation for FEM is mentioned below:

$$Y_{it} = \beta_{1i} + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + u_{it} \quad (7)$$

In the above equation, subscript (i) highlighted the individual country that made different countries with respect to their features. This FEM formulated using current research constructs is mentioned below:

Table 2. Descriptive statistics (Years).

	HTE	REP	PG	EI	REC	EG
2008	17.44	24.01	1.35	−58.56	18.95	3.43
2009	18.68	24.23	1.25	−53.68	18.69	−0.71
2010	18.14	25.04	1.18	−46.55	18.35	5.07
2011	17.43	25.46	1.15	−55.25	18.23	4.35
2012	18.19	26.09	1.31	−53.05	18.51	3.63
2013	17.98	26.69	1.27	−49.27	18.77	3.20
2014	17.99	26.14	1.25	−55.70	18.79	2.71
2015	18.69	27.13	1.20	−57.31	18.44	2.91
2016	18.67	12.07	1.18	−56.32	18.45	3.42
2017	18.77	12.56	1.06	−21.76	18.47	3.24
2018	18.52	17.04	1.02	−32.76	17.75	2.81
2019	18.59	16.25	1.01	−12.54	16.34	2.22

Here, HTE represents high technology exports, REP means renewable energy production, PG represents population growth, EI stands for energy import, REC means renewable energy consumption and EG stands for economic growth.
Source: Researchers' estimations.

$$HTE_{it} = \beta_{1i} + \beta_2 REP_{it} + \beta_3 REC_{it} + \beta_4 EI_{it} + \beta_5 EG_{it} + \beta_6 PG_{it} + u_{it} \quad (8)$$

The article has investigated the relationships between the understudy constructs using the GMM because the model usually has heterogeneity issues. The GMM equation is given as under:

$$Y_{it} = \delta Y_{i,\ t-1} + \beta_1 X_{1it} + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + u_{it} + \varepsilon_{it} \quad (9)$$

In addition, the GMM model is considered the appropriate model when the model have autocorrelation along with heteroscedasticity issues and the estimation equation for GMM model with understudy variables are given as under:

$$HTE_{it} = \delta HTE_{i,\ t-1} + \beta_1 REP_{it} + \beta_2 REC_{it} + \beta_3 EI_{it} + \beta_4 EG_{it} + \beta_5 PG_{it} + u_{it} + \varepsilon_{it} \quad (10)$$

4. Research findings

The results show the descriptive statistics of all the constructs with respect to the years. Table 2 shows that in 2008, HTE was 17.44%, while in 2019, it was 18.59%. In addition, the findings also show that in 2008, REP was 24.10%, while in 2019, it was 16.25%. Moreover, in 2008, PG was 1.35%, while in 2019, it was 1.01%, while in 2008, EI was −58.56%, while in 2019, it was −12.54%. Finally, in 2008, REC was 18.95%, while in 2019, it was 16.34%, while in 2008, EG was 3.43%, while in 2019, it was 2.22%.

The results show the descriptive statistics of all the constructs with respect to the selected counties. Table 3 shows that Belgium was at the top where HTE was 31.15%, while Saudi Arabia was at the bottom where HTE was only 0.76%. In addition, Norway was at the top where REP was 97.40%, while Saudi Arabia was at the bottom where REP was 0.00%. Moreover, Japan was at the top where PG was 2.85%, while Brazil was at the bottom where PG was only −0.11%. Furthermore, Singapore was at

Table 3. Descriptive statistics (Country).

	HTE	REP	PG	EI	REC	EG
USA	21.77	11.56	0.72	16.79	8.69	2.63
Norway	21.17	97.40	1.06	−568.76	58.20	1.09
Australia	18.31	10.88	1.64	−157.97	8.66	1.73
Netherland	24.91	10.81	0.48	18.84	5.21	1.25
Switzerland	23.14	57.62	1.06	50.86	22.17	0.47
Germany	16.78	21.29	0.08	60.70	13.29	1.69
Brazil	18.20	11.67	−0.11	88.32	5.58	4.31
Canada	15.64	62.55	1.11	−58.62	22.28	3.08
Singapore	51.31	1.45	1.81	97.77	0.58	1.47
Belgium	31.15	1.39	0.50	81.75	2.06	7.99
Iran	11.31	16.33	0.09	−82.48	3.33	3.68
China	30.82	19.72	0.49	12.32	12.46	5.40
Taiwan	1.88	31.01	2.13	23.50	45.74	6.18
Indonesia	9.40	13.16	1.27	−93.77	30.27	5.61
India	28.40	38.33	1.01	−18.53	34.35	1.00
Japan	0.86	7.47	2.85	−252.82	1.03	1.54
Turkey	7.74	29.58	1.04	2.92	9.17	5.33
South Korea	6.13	0.99	1.46	−15.01	10.69	3.23
Thailand	2.35	69.48	2.45	0.73	76.06	1.69
Saudi Arabia	0.76	0.00	2.57	−217.15	0.00	1.12

Here, HTE represents high technology exports, REP means renewable energy production, PG represents population growth, EI stands for energy import, REC means renewable energy consumption and EG stands for economic growth.
Source: Researchers' estimations.

the top, where EI was 97.77%, while Norway was at the bottom, where EI was only −568.76%. Additionally, Thailand was at the top where REC was 76.06%, while Saudi Arabia was at the bottom where REC was only 0.00%. Finally, Belgium was at the top where EG was 7.99%, while Switzerland was at the bottom where EG was only 0.47%.

The current article has executed the descriptive statistics that show the variables minimum and maximum values and the total observations. In addition, it also shows the mean and standard deviation of the understudy constructs. The statistics have been highlighted that the mean value of HTE is 19.605 while the average value of REP is 30.195. Moreover, the statistics have also been highlighted that the mean value of EI is −124.579 while the average value of PG is 1.248. Finally, the statistics have also been highlighted that the mean value of REC is 21.227 while the average value of EG is 4.126. The total observation of the study was 240 (20 countries x 12 Years). These values are mentioned as under in Table 4.

Moreover, the current article also shows the correlation among the understudy constructs using the matrix of correlation that provides just direction, not the significance. The statistics have been shown that REP, REC, PG and EG have a positive association with HTE. However, the results also indicated that EI has a negative association with HTE. The results also show that if 1% changes in REP, the HTE will change by 25.6% in the same direction. Moreover, the results also investigated that if one unit increase in PG, then the HTE will also increase by 0.005 units. The results also show that if 1% changes in EI, the HTE will change by 28.7% in the opposite direction. Moreover, the results also investigated that if one unit increase in REC, then the HTE will also increase by 0.119 units. Finally, the results also show that if 1% changes in EG, the HTE will change by 53.9% in the same direction. These values are mentioned as under in Table 5.

Table 4. Descriptive statistics (Overall).

Variable	Obs	Mean	Std. Dev.	Min	Max
HTE	240	19.605	5.574	0.679	53.437
REP	240	30.195	8.208	0.000	97.771
EI	240	−124.579	31.644	−568.77	97.786
PG	240	1.248	0.260	0.087	2.946
REC	240	21.227	9.834	0.000	77.399
EG	240	4.126	0.331	0.423	7.999

Here, HTE represents high technology exports, REP means renewable energy production, PG represents population growth, EI stands for energy import, REC means renewable energy consumption and EG stands for economic growth.
Source: Researchers' estimations.

Table 5. Matrix of correlations.

Variables	HTE	REP	EI	PG	REC	EG
HTE	1.000					
REP	0.256	1.000				
EI	−0.287	−0.302	1.000			
PG	0.005	0.072	−0.489	1.000		
REC	0.119	−0.400	0.657	−0.373	1.000	
EG	0.539	0.005	−0.070	0.001	0.264	1.000

Here, HTE represents high technology exports, REP means renewable energy production, PG represents population growth, EI stands for energy import, REC means renewable energy consumption and EG stands for economic growth.
Source: Researchers' estimations.

Additionally, the current study also checked the multicollinearity using VIF that indicated the correlation among the predictors. If the values of VIF are not higher than five, then the multicollinearity assumption proved as valid. The statistics have found that all the values are lower than five, showing that the multicollinearity assumption proved as valid.

The results of robust standard error indicated that green energy, such as renewable energy production and renewable energy consumption, along with economic factors such as economic growth, have a positive association with technological changes in developing and developed countries. The results also show that if 1% changes in REP, the HTE will change by 83.4% in the same direction. Moreover, the results also investigated that if one unit increase in REC, then the HTE will also increase by 0.287 units. In addition, the results also investigated that if one unit increase in EG, then the HTE will also increase by 0.012 units. However, the results also indicated that energy import and population growth have a negative association with technological changes in developing and developed countries. Thus, the results also show that if 1% changes in EI, the HTE will change by 44.4% in the opposite direction. Finally, the results also show that if 1% changes in PG, the HTE will change by 23.3% in the opposite direction. The R-squared value also exposed that 47.50% changes in HTE are due to all predictors selected by the researchers. These values are mentioned as under in Table 6.

The study also executed the Hausman test to select the suitable regression model among FEM and random model. The results exposed that the probability value is not bigger than 0.05, which shows FEM is suitable. If the Hausman test probability value is not less than 0.05, then the random model is appropriate but if the probability value is less than 0.05, then FEM is suitable.

Table 6. Robust standard error.

HTE	Beta	S.D.	t	P > t	L.L.	U.L.
REP	0.834	0.131	6.390	0.000	0.561	1.107
EI	−0.444	0.087	−5.120	0.000	−0.625	−0.263
PG	−0.233	0.072	−3.250	0.004	−0.382	−0.083
REC	0.287	0.066	4.360	0.000	0.149	0.425
EG	0.012	0.001	15.470	0.000	0.010	0.013
_cons	2.904	0.927	3.130	0.005	0.965	4.844
R-squared 0.4750 Number of Observation 240						
Root MSE 0.4206 Prob. > F 0.000						

Here, HTE represents high technology exports, REP means renewable energy production, PG represents population growth, EI stands for energy import, REC means renewable energy consumption and EG stands for economic growth.
Source: Researchers' estimations.

Table 7. Fixed effect model.

HTE	Beta	S.D.	t-value	p-value	L.L.	U.L.	Sig
REP	1.019	0.175	5.82	0.000	0.674	1.364	***
EI	−0.698	0.083	−8.36	0.000	−0.863	−0.533	***
PG	−0.459	0.330	−1.39	0.065	−1.109	−1.191	*
REC	0.204	0.114	1.79	0.075	0.021	0.429	*
EG	0.012	0.002	7.35	0.000	0.009	0.016	***
Constant	5.320	0.622	8.56	0.000	4.095	6.546	***
R-squared		0.573		Number of obs		240	
F-test		57.100		Prob > F		0.000	

Here, HTE represents high technology exports, REP means renewable energy production, PG represents population growth, EI stands for energy import, REC means renewable energy consumption and EG stands for economic growth. *** $p<.01$, ** $p<.05$, * $p<.1$.
Source: Researchers' estimations.

The results of FEM indicated that green energy, such as renewable energy production and renewable energy consumption, along with economic factors such as economic growth, have a positive association with technological changes in developing and developed countries. The results also show that if 1% changes in REP, the HTE will change by 101.9% in the same direction. Moreover, the results also investigated that if one unit increase in REC, then the HTE will also increase by 0.204 units. In addition, the results also investigated that if one unit increase in EG, then the HTE will also increase by 0.012 units. However, the results also indicated that energy import and population growth have a negative association with technological changes in developing and developed countries. Thus, the results also show that if 1% changes in EI, the HTE will change by 69.8% in the opposite direction. Finally, the results also show that if 1% changes in PG, the HTE will change by 45.9% in the opposite direction. The R-squared value also exposed that 57.30% changes in HTE are due to all predictors selected by the researchers. These values are mentioned as under in Table 7.

The results of GMM indicated that REP and REC, along with economic factors such as economic growth, have a positive association with technological changes in developing and developed countries. The results also show that if 1% changes in REP, the HTE will change by 0.829% in the same direction. Moreover, the results also investigated that if one unit increase in REC, then the HTE will also increase by 0.736 units. In addition, the results also investigated that if one unit increase in EG, then the HTE will also increase by 0.362 units. However, the results also indicated

Table 8. Generalized method of moments (GMM).

HTE	Beat	S.D.	t-value	p-value	L.L.	U.L.	Sig
REP	0.829	0.290	2.86	0.034	0.239	2.309	**
EI	−0.931	0.342	−2.72	0.037	−1.547	−0.532	**
PG	−1.829	0.582	−3.14	0.024	−1.890	−0.327	**
REC	0.736	0.201	3.66	0.018	0.141	1.577	**
EG	0.362	0.034	10.64	0.000	0.014	2.020	***
Mean dependent var		1.563	SD dependent var		0.567		
Number of obs		240.000	F-test		63.439		

Here, HTE represents high technology exports, REP means renewable energy production, PG represents population growth, EI stands for energy import, REC means renewable energy consumption and EG stands for economic growth.
*** $p<.01$, ** $p<.05$, * $p<.1$.
Source: Researchers' estimations.

that energy import and population growth have a negative association with technological changes in developing and developed countries. Thus, the results also show that if 1% changes in EI, the HTE will change by 0.931% in the opposite direction. Finally, the results also show that if 1% changes in PG, the HTE will change by 1.829% in the opposite direction. These values are mentioned as under in Table 8.

5. Discussion and implications

The study results have indicated that renewable energy production is in a positive association with technological changes. The study results are supported by the previous study of Schmidt and Sewerin (2019), which analyzes the ecological consequences of renewable energy production and its impact on the economy. The study states that the techniques or processes to produce renewable energy such as wind power, hydropower, geothermal power, solar power, biomass, and biofuel do not cause pollution spread within the country. That is why the commercial points that need the energy to fulfil the business needs change the pattern of energy production and energy consumption like the change in the relevant techniques or technology used. These results are also in line with the previous study of Polzin et al. (2019), which shows that as the production of renewable energy is an ecological friendly program to produce energy for both domestic and commercial purposes, this encourages the change in the technologies, or processes and skills to use technology so that the renewable energy can be used. These results are also supported by the previous study of Miremadi et al. (2019), which states that the production of renewable energy is an effective way to reduce global warming and rise in the ocean level. Thus, a change in the technology, its qualities or processes to use must be made so that the energy which can be replenished and does not cause wastes can be applied.

The study results have also indicated that renewable energy consumption is in a positive relationship to technological changes. These results are in line with the past study of Fan and Hao (2020) which implies that when there is a trend in the economy to use renewable energy for the sake of protection of work environment within the organization and the natural environment for the safety of natural resources and health of livings, the business organizations focus on the quality of technology used. They apply such technology, which can be carried on with renewable energy like machinery, which requires low voltage power. These results are supported by the

previous study of Shahzad et al. (2020), which shows the inclination of the business organizations to consume renewable energy to ensure a clean working environment. According to this study, for better performance in the competitive market, organizations need a healthy work environment so that the employees perform efficiently. This is possible if the renewable energy resources are consumed for energy purposes as the consumption of renewable energy do not produce harmful gases, chemicals and leave no contaminating wastes. In order to change the energy sources, the organization has to bring change in its technology, techniques, methods, and skills needed for manufacturing or operating other business functions.

It has also been indicted by the study results that the import of energy has negative impacts on technological changes. These results are supported by the past study of Ağbulut (2019), which suggests that the import of energy resources for meeting domestic energy needs affects the quality of the inland environment, the work environment within the domestic organizations, and the health of living beings. So, the facility of the import of energy determines the type of technology and techniques used within the country for economic activities. These results are supported by the previous study of Lam et al. (2019), which shows that the purchase of renewable energy resources from foreign countries cannot be a useful way to handle the environmental issues within the country caused by the expansion of economic activities. This brings an unfavourable change within the technology and processes used for the manufacturing of goods, rendering of services and transportation, which is the critical part of society and economy.

The study results have also shown that the economic growth of the country has a significant impact on technological changes. These results agree with the study of Wang and Feng (2019) which examines that the country which is making rapid progress from an economic point of view, the individuals, organizations, and government institutions have enough financial resources to spend on the environmental programs, economic improvement, and construction projects. These financial resources enable them to bring changes in the relevant technologies and processes for information, communication and production and for performing different other specific tasks. These results also agree with the study of Klofsten et al. (2019), which states that when the country is making economic growth at a high rate, there is an expansion in the business activities like agriculture, production of goods, rendering of services, and transportation. For performing all these activities, new technology, innovative processes, and improved techniques are required. These results are supported by the past study of Sharma et al., (2021), which reveals that in the fast-emerging economies, the organizations pay heed to innovation in the technologies, techniques, and processes and development of innovative knowledge or skills as in this way, sustainability can be created in the economic development.

The study results have also indicated that population growth has a negative association with technology change. These results are in line with the previous study of Lutz (2017), which shows that in the countries where the population growth rate is high, the basic and additional needs of life are also in large. In order to meet the increased needs of people, there is a resultant increase in economic activities and employment. This gives rise to the use of technology, the invention of new

technologies, or improvement in the available technologies to meet the increasing requirements but due to lack of sources it is not possible for the developing countries. These results are supported by the past study of Bucci et al. (2019), which highlights that the increase in the population growth rate, on one side, increases the need for more productivity and more employment while on the other side, it also increases the human resources for the economy. The skilled and aware human resources bring change in the technologies, techniques, and processes but it is not possible for the developing economies.

The study carries both theoretical and empirical implications. The current study has a theoretical significance as it contributes greatly to the ecological and economic-based literature. The study focuses on technology (products and processes) as an integral part of society and the economy and shows the importance of technological changes. This study analyzes the influences of ecological consequences of green energy such as renewable energy production, renewable energy consumption, and energy import along with economic growth and population growth on the technological changes. Mostly, the influences of green energy on the environment and technological changes have been addressed without the description of its dimensions, such as ecological consequences of green energy such as renewable energy production, renewable energy consumption, and energy import. But the current study describes the ecological consequences of green energy with three dimensions of renewable energy production, renewable energy consumption, and energy import while analysing the technological changes within the economy; thus, it is an addition to the literature. However, the influences of the ecological consequences of green energy on technological changes have simply been explored without analysing the presence of economic growth and population growth. So, the present study is an exception in the literature. Similarly, the analysis of ecological consequences of renewable energy consumption and renewable energy production at the same time to determine the technological changes is a new concept in the literature. The current, which is based on empirical research about technological changes, has a remarkable significance in the fast-emerging economies developing economies. This study is important to the economists and environmental regulators as it serves as a guideline to them while formulating their policies to overcome environmental caused by humans or economic activities and to put the economy towards innovation to meet the global competition. This study guides the readers on how ecological improvement and technological development are possible. This article guides the regulators while developing effective policies regarding technology changes in the country. This article is also helpful for the upcoming literature while investigating this topic in future. This study shows that with the encouragement of green energy like renewable energy production, renewable energy consumption, and energy import. It also highlights those positive technological changes occur because of the ecological consequences of such as renewable energy production, renewable energy consumption, with effective management of economic growth.

6. Conclusion and limitations

Environmental problems as a result of exponential increase in business activities have the global issue. Almost all the countries are facing problems. Environmental degradation affects adversely both the society and economy of a country. Moreover, the

competition in the global market has been increasing at a high rate and the world getting modern. People want change and newness in everything. They also want agility along with reliability in the sellers' products and services. In order to respond to innovative and environmental requirements of consumers, a change in resources, techniques, and processes is needed. This study was conducted to remove these issues of environmental and innovation performance of the economy. The purpose of the study was to check the role of ecological consequences of green energy such as renewable energy production, renewable energy consumption, and energy import in bringing the technological changes and the current study examines the ecological consequences of green energy along with economic growth and population growth on the technological changes. In order to achieve study objectives, authors analysed the impact of ecological consequences of three categories of green energy such as renewable energy production, renewable energy consumption, and energy import on the technological changes and the study also analysed the economic growth and population growth in ten developed and ten developing countries. For data collection, the selected developed countries were Norway, Australia, Switzerland, Netherlands, USA, Germany, New Japan, Canada, Singapore, and South Korea, and developing countries were Russia, China, Pakistan, Indonesia, Vietnam, Iraq, Argentina, South Africa, Guinea, and Saudi Arabia. The results of the study are based on this empirical analysis. These results revealed that renewable energy production does not cause the emission of harmful substances or wastes. Instead, it is an effective source to overcome the environmental issues of global warming, lack of oxygen, and rise in the level of the ocean. The improvement in the environment encourages technological changes required for energy production. The results also indicated that renewable energy consumption for meeting the energy needs of business organizations brings improvement in technological skills and processes, which enables the adoption of innovative technologies for production and other business operations. The results of the study showed that the ability of the domestic business firms to import renewable energy resources, solar panels, turbines, and biomass, brings a change in the efficiency of technologies within the economy. The results also concluded that the rise in economic activities, including production of goods and rendering or all sorts of services, increases the number of technologies applied and improvement in the efficiency of technologies and effectiveness of different economic techniques. The study also inferred that population growth increases the use of technologies or technical processes both at a domestic or commercial level; thus, it leads to technological changes but difficult for the developing countries.

Though the current study achieves an exceptional position in the literature and has success in practical economies, still it has certain limitations. Future can prove their intellectual power by removing these limitations in future studies. First, the study analyses the influences of only a single factor ecological consequences of green energy with three dimensions renewable energy production, renewable energy consumption, and energy import on the technological changes. Many other factors like green finances, organizational policies, and global competitiveness are critical to technological changes, but these factors have not been addressed. Thus, the scope of the study is limited, and future authors are recommended to address the influences

of more factors on technological changes. This study checks the environmental consequences of only green energy, while the environmental consequences of non-renewable energy have utterly been ignored, which are also significant in this regard. The scope of the study is also limited in this sense. The authors who will be willing to investigate the technology role in the economy must also analyse the environmental consequences of non-renewable energy.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research is partly funded by Van Lang University, Vietnam. This research is also partly funded by University of Economics Ho Chi Minh City, Vietnam.

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References

Abdin, I. F., & Zio, E. (2018). An integrated framework for operational flexibility assessment in multi-period power system planning with renewable energy production. *Applied Energy*, *222*, 898–914. https://doi.org/10.1016/j.apenergy.2018.04.009

Ağbulut, Ü. (2019). Turkey's electricity generation problem and nuclear energy policy. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *41*(18), 2281–2298. https://doi.org/10.1080/15567036.2019.1587107

Agustina, N., Pramana, S. (2019). The impact of development and government expenditure for information and communication technology on Indonesian economic growth. *Journal of Business Economics and Environmental Studies*, *9*(4), 5–13. https://doi.org/10.13106/jbees.2019.vol9.no4.5

Ali, A., Tufa, R. A., Macedonio, F., Curcio, E., & Drioli, E. (2018). Membrane technology in renewable-energy-driven desalination. *Renewable and Sustainable Energy Reviews*, *81*, 1–21. https://doi.org/10.1016/j.rser.2017.07.047

Alvarez-Herranz, A., Balsalobre-Lorente, D., Shahbaz, M., & Cantos, J. M. (2017). Energy innovation and renewable energy consumption in the correction of air pollution levels. *Energy Policy*, *105*, 386–397. https://doi.org/10.1016/j.enpol.2017.03.009

Asongu, S. A., & Odhiambo, N. M. (2020). Foreign direct investment, information technology and economic growth dynamics in Sub-Saharan Africa. *Telecommunications Policy*, *44*(1), 101838. https://doi.org/10.1016/j.telpol.2019.101838

Bamati, N., & Raoofi, A. (2020). Development level and the impact of technological factor on renewable energy production. *Renewable Energy*, *151*, 946–955. https://doi.org/10.1016/j.renene.2019.11.098

Berger, T. (2019). Adopting a new technology: Potatoes and population growth in the periphery. *The Economic History Review*, *72*(3), 869–896. https://doi.org/10.1111/ehr.12743

Bilan, Y., Hussain, H. I., Haseeb, M., & Kot, S. (2020). Sustainability and economic performance: Role of organizational learning and innovation. *Engineering Economics*, *31*(1), 93–103. https://doi.org/10.5755/j01.ee.31.1.24045

Bucci, A., Eraydın, L., & Müller, M. (2019). Dilution effects, population growth and economic growth under human capital accumulation and endogenous technological change. *Journal of Macroeconomics*, *62*, 103050–103121. https://doi.org/10.1016/j.jmacro.2018.08.003

Chin, V., Ioannidis, J. P., Tanner, M. A., & Cripps, S. (2021). Effect estimates of COVID-19 non-pharmaceutical interventions are non-robust and highly model-dependent. *Journal of Clinical Epidemiology*, *136*, 96–132.

Chien, F., Sadiq, M., Nawaz, M. A., Hussain, M. S., Tran, T. D., & Le Thanh, T. (2021a). A step toward reducing air pollution in top Asian economies: The role of green energy, eco-innovation, and environmental taxes. *Journal of Environmental Management*, *297*, 113420. https://doi.org/10.1016/j.jenvman.2021.113420

Chien, F., Hsu, C. C., Ozturk, I., Sharif, A., & Sadiq, M. (2022). The role of renewable energy and urbanization towards greenhouse gas emission in top Asian countries: Evidence from advance panel estimations. *Renewable Energy*, *186*, 207–216. https://doi.org/10.1016/j.renene.2021.12.118

Chien, F., Zhang, Y., Sadiq, M., & Hsu, C. C. (2021b). Financing for energy efficiency solutions to mitigate opportunity cost of coal consumption: An empirical analysis of Chinese industries. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-15701-9

Chien, F., Sadiq, M., Kamran, H. W., Nawaz, M. A., Hussain, M. S., & Raza, M. (2021c). Co-movement of energy prices and stock market return: Environmental wavelet nexus of COVID-19 pandemic from the USA, Europe, and China. *Environmental Science and Pollution Research*, https://doi.org/10.1007/s11356-021-12938-2

Dlalisa, S. F., & Govender, D. W. (2020). Challenges of acceptance and usage of a learning management system amongst academics. *International Journal of Ebusiness and Egovernment Studies*, *12*(1), 63–78.

Douthwaite, B., & Hoffecker, E. (2017). Towards a complexity-aware theory of change for participatory research programs working within agricultural innovation systems. *Agricultural Systems*, *155*, 88–102. https://doi.org/10.1016/j.agsy.2017.04.002

Ehsanullah, S., Tran, Q. H., Sadiq, M., Bashir, S., Mohsin, M., & Iram, R. (2021). How energy insecurity leads to energy poverty? Do environmental consideration and climate change concerns matters. *Environmental Science and Pollution Research*, *28*(39), 55041–55052. https://doi.org/10.1007/s11356-021-14415-2

Fan, W., & Hao, Y. (2020). An empirical research on the relationship amongst renewable energy consumption, economic growth and foreign direct investment in China. *Renewable Energy*, *146*, 598–609. https://doi.org/10.1016/j.renene.2019.06.170

Freire, C. (2019). Economic diversification: A model of structural economic dynamics and endogenous technological change. *Structural Change and Economic Dynamics*, *49*, 13–28. https://doi.org/10.1016/j.strueco.2019.03.005

Flores, A., & Chang, V. (2019). Relación entre la demanda de transporte y el crecimiento económico: Análisis dinámico mediante el uso del modelo ARDL. *Cuadernos de Economía*, *42*(122), 145–163. https://doi.org/10.32826/cude.v42i122.123

Gadeikiene, A., & Svarcaite, A. (2021). Impact of consumer environmental consciousness on consumer perceived value from sharing economy. *Engineering Economics*, *32*(4), 350–361. https://doi.org/10.5755/j01.ee.32.4.28431

García-Olivares, A., Solé, J., & Osychenko, O. (2018). Transportation in a 100% renewable energy system. *Energy Conversion and Management*, *158*, 266–285. https://doi.org/10.1016/j.enconman.2017.12.053

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, *24*, 38–50. https://doi.org/10.1016/j.esr.2019.01.006

Glover, D., Sumberg, J., Ton, G., Andersson, J., & Badstue, L. (2019). Rethinking technological change in smallholder agriculture. *Outlook on Agriculture*, *48*(3), 169–180. doi: https://doi.org/10.1177/0030727019864978

Gudanowska, A. E., Kononiuk, A., & Dębkowska, K. (2020). The application of cluster analysis for the selection of key competences of future-oriented entrepreneurs. *Engineering Economics*, *31*(5), 565–574. https://doi.org/10.5755/j01.ee.31.5.25194

Gutiérrez, E., & Teshima, K. (2018). Abatement expenditures, technology choice, and environmental performance: Evidence from firm responses to import competition in Mexico. *Journal of Development Economics*, *133*, 264–274. https://doi.org/10.1016/j.jdeveco.2017.11.004

Han, J.-S., & Lee, J.-W. (2020). Demographic change, human capital, and economic growth in Korea. *Japan and the World Economy*, *53*, 100984. https://doi.org/10.1016/j.japwor.2019.100984

Hassan, S. T., Khan, D., Zhu, B., & Batool, B. (2022). Is public service transportation increase environmental contamination in China? The role of nuclear energy consumption and technological change. *Energy*, *238*, 121890. https://doi.org/10.1016/j.energy.2021.121890

Heinrich, N. E. L., Blaauw, D., & Pretorius, A. (2020). Investigating the Hungarian money demand function: Possible implications for monetary policy. *International Journal of Economics and Finance Studies*, *12*(1), 71–87.

Huang, J., Du, D., & Tao, Q. (2017). An analysis of technological factors and energy intensity in China. *Energy Policy*, *109*, 1–9. https://doi.org/10.1016/j.enpol.2017.06.048

Huang, S. Z., Sadiq, M., & Chien, F. (2021a). The impact of natural resource rent, financial development, and urbanization on carbon emission. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-16818-7

Huang, S. Z., Sadiq, M., & Chien, F. (2021b). Dynamic nexus between transportation, urbanization, economic growth and environmental pollution in ASEAN countries: Does environmental regulations matter? *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-17533-z

Huang, S. Z., Chien, F., & Sadiq, M. (2021c). A gateway towards a sustainable environment in emerging countries: The nexus between green energy and human Capital. *Economic Research-Ekonomska Istraživanja*. https://doi.org/10.1080/1331677X.2021.2012218

Hwang, W.-S., & Shin, J. (2017). ICT-specific technological change and economic growth in Korea. *Telecommunications Policy*, *41*(4), 282–294. https://doi.org/10.1016/j.telpol.2016.12.006

Jelača, M. S., Milićević, N., Bjekić, R., & Petrov, V. (2020). The effects of environment uncertainty and leadership styles on organisational innovativeness. *Engineering Economics/ Inžinerinė ekonomika*, *31*(4), 472–486.

Jia, P., Li, K., & Shao, S. (2018). Choice of technological change for China's low-carbon development: Evidence from three urban agglomerations. *Journal of Environmental Management*, *206*, 1308–1319. https://doi.org/10.1016/j.jenvman.2017.08.052

Jokanović, B., Lalic, B., Milovančević, M., Simeunović, N., & Marković, D. (2017). Economic development evaluation based on science and patents. *Physica A: Statistical Mechanics and Its Applications*, *481*, 141–145. https://doi.org/10.1016/j.physa.2017.04.015

Kahan, B. C. (2014). Accounting for centre-effects in multicentre trials with a binary outcome – when, why, and how? *BMC Medical Research Methodology*, *14*(1). https://doi.org/10.1186/1471-2288-14-20

Kikulwe, E., & Asindu, M. (2020). Consumer demand and prospects for commercialization of nutritionally enhanced GM bananas in Uganda. *AgBioforum*, *22*(1), 13–24.

Klofsten, M., Fayolle, A., Guerrero, M., Mian, S., Urbano, D., & Wright, M. (2019). The entrepreneurial university as driver for economic growth and social change-Key strategic challenges. *Technological Forecasting and Social Change*, *141*, 149–158. https://doi.org/10.1016/j.techfore.2018.12.004

Koloba, H. A. (2020). Purchase intention towards environmentally friendly products among consumers in South Africa. Applying the theory of planned behaviour. *International Journal of Business and Management Studies*, *12*(1), 34–49.

Kumar, A., & Samadder, S. R. (2017). A review on technological options of waste to energy for effective management of municipal solid waste. *Waste Management (New York, N.Y.)*, *69*, 407–422. https://doi.org/10.1016/j.wasman.2017.08.046

Lam, K. L., Kenway, S. J., Lane, J. L., Islam, K. N., & de Berc, R. B. (2019). Energy intensity and embodied energy flow in Australia: An input-output analysis. *Journal of Cleaner Production*, *226*, 357–368. https://doi.org/10.1016/j.jclepro.2019.03.322

Langkau, S., & Espinoza, L. A. T. (2018). Technological change and metal demand over time: What can we learn from the past? *Sustainable Materials and Technologies*, *16*, 54–59. https://doi.org/10.1016/j.susmat.2018.02.001

Li, K., Yan, Y., & Zhang, X. (2021). Carbon-abatement policies, investment preferences, and directed technological change: Evidence from China. *Technological Forecasting and Social Change*, *172*, 121015–121136. https://doi.org/10.1016/j.techfore.2021.121015

Li, W., Chien, F., Kamran, H., W., Aldeehani, T., M., Sadiq, M., Nguyen, V., C., & Taghizadeh-Hesary, F. (2021). The nexus between COVID-19 fear and stock market volatility. *Economic Research-Ekonomska Istraživanja*. https://doi.org/10.1080/1331677X.2021.1914125

Liu, Z., Tang, Y. M., Chau, K. Y., Chien, F., Iqbal, W., & Sadiq, M. (2021a). Incorporating strategic petroleum reserve and welfare losses: A way forward for the policy development of crude oil resources in South Asia. *Resources Policy*, *74*, 102309. https://doi.org/10.1016/j.resourpol.2021.102309

Liu, Z., Lan, J., Chien, F., Sadiq, M., & Nawaz, M. A. (2021b). Role of tourism development in environmental degradation: A step towards emission reduction. *Journal of Environmental Management*, *303*, 114078. https://doi.org/10.1016/j.jenvman.2021.114078

Lutz, W. (2017). How population growth relates to climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(46), 12103–12105. https://doi.org/10.1073/pnas.1717178114

Lyytimäki, J. (2018). Renewable energy in the news: Environmental, economic, policy and technology discussion of biogas. *Sustainable Production and Consumption*, *15*, 65–73. https://doi.org/10.1016/j.spc.2018.04.004

Ma, Q., Jia, P., & Kuang, H. (2021). Green efficiency changes of comprehensive transportation in China: Technological change or technical efficiency change? *Journal of Cleaner Production*, *304*, 127115–127135. https://doi.org/10.1016/j.jclepro.2021.127115

Matyushok, V., Krasavina, V., Berezin, A., & García, J. S. (2021). The global economy in technological transformation conditions: A review of modern trends. *Economic Research-Ekonomska Istraživanja*, *34*(1), 1471–1497. https://doi.org/10.1080/1331677X.2020.1844030

Miremadi, I., Saboohi, Y., & Arasti, M. (2019). The influence of public R&D and knowledge spillovers on the development of renewable energy sources: The case of the Nordic countries. *Technological Forecasting and Social Change*, *146*, 450–463. https://doi.org/10.1016/j.techfore.2019.04.020

Moslehpour, M., Chang, M. L., Pham, V. K., & Dadvari, A. (2022a). Adopting the configurational approach to the analysis of job satisfaction in Mongolia. *European Research on Management and Business Economics*, *28*(1), 100179. https://doi.org/10.1016/j.iedeen.2021.100179

Moslehpour, M., Al-Fadly, A., Ehsanullah, S., Chong, K. W., Xuyen, N. T. M., & Tan, L. P. (2022b). Assessing financial risk spillover and panic impact of Covid-19 on European and Vietnam stock market. *Environmental Science and Pollution Research*, *29*(19), 28226–28240. https://doi.org/10.1007/s11356-021-18170-2

Moslehpour, M., Ismail, T., Purba, B., & Wong, W. K. (2021). What makes GO-JEK Go in Indonesia? The influences of social media marketing activities on purchase intention. *Journal of Theoretical and Applied Electronic Commerce Research*, *17*(1), 89–103. https://doi.org/10.3390/jtaer17010005

Mullan, B., & Haqq-Misra, J. (2019). Population growth, energy use, and the implications for the search for extraterrestrial intelligence. *Futures*, *106*, 4–17. https://doi.org/10.1016/j.futures.2018.06.009

Ngo, C. N., & McCann, C. R. (2019). Rethinking rent seeking for technological change and development. *Journal of Evolutionary Economics*, *29*(2), 721–740. https://doi.org/10.1007/s00191-018-0591-3

Omwoma, S., Lalah, J. O., Kueppers, S., Wang, Y., Lenoir, D., & Schramm, K.-W. (2017). Technological tools for sustainable development in developing countries: The example of Africa, a review. *Sustainable Chemistry and Pharmacy*, *6*, 67–81. https://doi.org/10.1016/j.scp.2017.10.001

Othman, Z., Nordin, M. F. F., & Sadiq, M. (2020). GST fraud prevention to ensure business sustainability: A Malaysian case study. *Journal of Asian Business and Economic Studies*, *27*(3), 245–265. https://doi.org/10.1108/JABES-11-2019-0113

Overland, I. (2019). The geopolitics of renewable energy: Debunking four emerging myths. *Energy Research & Social Science*, *49*, 36–40. https://doi.org/10.1016/j.erss.2018.10.018

Piligrimienė, Ž., Banytė, J., Dovalienė, A., Gadeikienė, A., & Korzilius, H. (2021). Sustainable consumption patterns in different settings. *Engineering Economics*, *32*(3), 278–291. https://doi.org/10.5755/j01.ee.32.3.28621

Polzin, F., Egli, F., Steffen, B., & Schmidt, T. S. (2019). How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective. *Applied Energy*, *236*, 1249–1268. https://doi.org/10.1016/j.apenergy.2018.11.098

Przychodzen, W., & Przychodzen, J. (2020). Determinants of renewable energy production in transition economies: A panel data approach. *Energy*, *191*, 116583. https://doi.org/10.1016/j.energy.2019.116583

Pursiheimo, E., Holttinen, H., & Koljonen, T. (2019). Inter-sectoral effects of high renewable energy share in global energy system. *Renewable Energy*, *136*, 1119–1129. https://doi.org/10.1016/j.renene.2018.09.082

Rastogi, R. P., Pandey, A., Larroche, C., & Madamwar, D. (2018). Algal green energy–R&D and technological perspectives for biodiesel production. *Renewable and Sustainable Energy Reviews*, *82*, 2946–2969. https://doi.org/10.1016/j.rser.2017.10.038

Reinholz, D. L., & Andrews, T. C. (2020). Change theory and theory of change: What's the difference anyway? *International Journal of STEM Education*, *7*(1), 1–12. https://doi.org/10.1186/s40594-020-0202-3

Sadiq, M., Hsu, C. C., Zhang, Y., & Chien, F. S. (2021a). COVID-19 fear and volatility index movements: Empirical insights from ASEAN stock markets. *Environmental Science and Pollution Research*, *28*(47), 67167–67184. https://doi.org/10.1007/s11356-021-15064-1

Sadiq, M., Nonthapot, S., Mohamad, S., Chee Keong, O., Ehsanullah, S., & Iqbal, N. (2021b). Does green finance matters for sustainable entrepreneurship and environmental corporate social responsibility during Covid-19. ?*China Finance Review International*, *12*(2), 317–333. https://doi.org/10.1108/CFRI-02-2021-0038

Sadiq, M., Alajlani, S., Hussain, M. S., Ahmad, R., Bashir, F., & Chupradit, S. (2021c). Impact of credit, liquidity, and systematic risk on financial structure: Comparative investigation from sustainable production. *Environmental Science and Pollution Research*, https://doi.org/10.1007/s11356-021-17276-x.

Schmidt, T. S., & Sewerin, S. (2019). Measuring the temporal dynamics of policy mixes–An empirical analysis of renewable energy policy mixes' balance and design features in nine countries. *Research Policy*, *48*(10), 103557. https://doi.org/10.1016/j.respol.2018.03.012

Shahzad, K., Jianqiu, Z., Hashim, M., Nazam, M., & Wang, L. (2020). Impact of using information and communication technology and renewable energy on health expenditure: A case study from Pakistan. *Energy*, *204*, 117956. https://doi.org/10.1016/j.energy.2020.117956

Shao, S., Guo, L., Yu, M., Yang, L., & Guan, D. (2019). Does the rebound effect matter in energy import-dependent mega-cities? Evidence from Shanghai (China). *Applied Energy*, *241*, 212–228. https://doi.org/10.1016/j.apenergy.2019.03.007

Sharma, G. D., Rahman, M. M., Jain, M., & Chopra, R. (2021). Nexus between energy consumption, information and communications technology, and economic growth: An enquiry into emerging Asian countries. *Journal of Public Affairs*, *21*(2), 217–236. https://doi.org/10.1002/pa.2172

Shaw, R., Kim, Y-k., & Hua, J. (2020). Governance, technology and citizen behavior in pandemic: Lessons from COVID-19 in East Asia. *Progress in Disaster Science*, *6*, 100090–100126. https://doi.org/10.1016/j.pdisas.2020.100090

Sun, H., Edziah, B. K., Kporsu, A. K., Sarkodie, S. A., & Taghizadeh-Hesary, F. (2021). Energy efficiency: The role of technological innovation and knowledge spillover. *Technological Forecasting and Social Change*, *167*, 120659. https://doi.org/10.1016/j.techfore.2021.120659

Tan, L. P., Sadiq, M., Aldeehani, T. M., Ehsanullah, S., Mutira, P., & Vu, H. M. (2021). How COVID-19 induced panic on stock price and green finance markets: Global economic recovery nexus from volatility dynamics. *Environmental Science and Pollution Research*, https://doi.org/10.1007/s11356-021-17774-y

Vlaev, I., & Dolan, P. (2015). Action change theory: A reinforcement learning perspective on behavior change. *Review of General Psychology*, *19*(1), 69–95. https://doi.org/10.1037/gpr0000029

Wang, M., & Feng, C. (2019). Decoupling economic growth from carbon dioxide emissions in China's metal industrial sectors: A technological and efficiency perspective. *The Science of the Total Environment*, *691*, 1173–1181. https://doi.org/10.1016/j.scitotenv.2019.07.190

Xiang, H., Ch, P., Nawaz, M. A., Chupradit, S., Fatima, A., & Sadiq, M. (2021). Integration and economic viability of fueling the future with green hydrogen: An integration of its determinants from renewable economics. *International Journal of Hydrogen Energy*, *46*(77), 38145–38162. https://doi.org/10.1016/j.ijhydene.2021.09.067

Xueying, W., Sadiq, M., Chien, F., Ngo, T. Q., & Nguyen, A. T. (2021). Testing role of green financing on climate change mitigation: Evidences from G7 and E7 countries. *Environmental Science and Pollution Research*, *28*, 66736–66750. https://doi.org/10.1007/s11356-021-15023-w

Yousaf, Z., Radulescu, M., Nassani, A., Aldakhil, A. M., & Jianu, E. (2021). Environmental management system towards environmental performance of hotel industry: Does corporate social responsibility authenticity really matter? *Engineering Economics*, *32*(5), 484–498. https://doi.org/10.5755/j01.ee.32.5.28619

Zecca, E., & Nicolli, F. (2021). Inequality, democracy and green technological change. *Journal of Cleaner Production*, *306*, 127061–127143. https://doi.org/10.1016/j.jclepro.2021.127061

Zhao, L., Zhang, Y., Sadiq, M., Hieu, V. M., & Ngo, T. Q. (2021). Testing green fiscal policies for green investment, innovation and green productivity amid the COVID-19 era. *Economic Change and Restructuring*, https://doi.org/10.1007/s10644-021-09367-z

Zhu, J., Niu, L., Ruth, M., & Shi, L. (2018). Technological change and energy efficiency in large Chinese firms. *Ecological Economics*, *150*, 241–250. https://doi.org/10.1016/j.ecolecon.2018.04.009