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Research Paper

Role of knowledge economy in managing demand-based environmental Kuznets Curve

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ABSTRACT

Aggregate demand or supply at equilibrium is commonly used as a representative of the macroeconomic activity of an economy whereby aggregate demand denotes the behaviour of individuals and households. However, aggregate demand can also directly affect environmental deterioration via changes in aggregate production. This study tried to explore this relationship, known as the demand-based Environmental Kuznets Curve (Demand EKC) and the role of different knowledge economy indicators. Knowledge economy indicators are proposed to influence consumption patterns, altering the demand EKC that empirical studies have understudied. For this purpose, secondary data for 147 countries were collected from 2008 to 2018, also classified as development-wise. This study found that aggregate demand significantly affects carbon emissions. The long-run results are estimated using the Fully Modified Ordinary Least Square method. Controlling factors like renewable energy consumption, population density, and financial development significantly affect carbon emissions in sample countries. This study has incorporated four pillars of a knowledge-based economy and the results showed that these indicators helped reduce consumption-related CO_2 emissions.

1. Introduction

Day by day, environmental problems are becoming challenging (Eke and McNally, 1996; Buckingham and Turner, 2008). There was a time when people enjoyed a clean and healthy environment but, as the industrial revolution took place, environmental and atmospheric pollution started to emerge (Boubel et al., 2013). Economic growth at the cost of environmental and health deterioration is a considerable cost (Franchini et al., 2015). Higher economic growth increases higher friction which makes the economies polluted. Specifically, air pollution not only causes health problems but also creates economic losses like a reduction in the tourist trade, fruit crops, life expectancy, economic prosperity, and crimes (Faith, 2012; Fatima et al., 2021; Yasmin et al., 2021). It is true that high economic growth increases the standard of living but also impairs the environment (Shahbaz et al., 2016). An increasing trend in climate change is an example (https://www.ipcc.ch/). It is witnessed that carbon dioxide emissions grew by 1.4% in 2017 reaching a historic high of 32.5 GT (gigatons) universally (https://www.iea.org/news/global-energy-demand-grew-by-21-in-2017-and-carbon-emissions-rose-for-the-first-time-since-2014). This increasing trend is observed in significant economies (International Energy Agency, Global Energy & CO2 Status Report, 2017) of the world. So, this environmental challenge is global and many economies suffer from this. However, there are also international bodies to overcome environmental challenges, among them the United Nations Millennium Development Goals and Sustainable Development Goals (UN Sustainable Development Goals - https://www.un.org/sustainabledevelopment/sustainable-development-goals/) are noticeable. In short, ungoverned economic activities are blamed for environmental degradation whereby economic activities take time to self-adjust and care for posterity. A well-known notion that covers this behaviour is known as the Environmental Kuznets Curve (EKC). In short, it means today you grow, tomorrow you clean; hence EKC depicts an inverted U-shaped relationship between economic growth and carbon emissions (Özokcua and Özdemir, 2017; Sinha and Shahbaz, 2018; Usman et al., 2019; Altıntaş and Kassouri, 2020).

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Considering the significance of aggregate income on the environment (Iqbal et al., 2019; Bah et al., 2020), a channel of aggregate demand based EKC emerges. It links the general behaviour of households with environmental sustainability whereby Maslow's hierarchy of needs patterns would prevail when the economy develops, forming a curvilinear relationship of demand with the environment (Arshed et al., 2022). When demand increases, production tends to increase (Keynes, 1937) leading to increased footprints. To establish the relationship between aggregate demand with environmental deterioration the income level of the consumers is to be considered (Narayan et al., 2016). With increased income aggregate demand increases in two ways, either a direct increase in consumption or an increase in savings leading to an increase in production investments. Both cases result in increased production that, in turn, directly impacts the environment (Bah et al., 2020; Hassan et al., 2021).

Another interesting point is that environmental deterioration differs in income levels (Zhang et al., 2019) or the size of economic activity (Hassan et al., 2021) which means income significantly determines environmental degradation. Therefore, the EKC related to aggregate income is considered a demand based EKC. A significant consequence of increased aggregate demand is an increase in the ecological footprint (Destek and Sarkodie, 2019) which is the same as with aggregate supply (Ahmad et al., 2020). According to the definition of ecological footprint, an increase in aggregate demand increases the utilisation of resources 'how fast individuals utilise their resources and generate waste material.'(https://www.footprintnetwork.org/our-work/ecological-footprint/). This dimension of ecological footprint is hidden behind the aggregate demand channel of EKC. It can be reduced using an organised intervention which controls the aggregate demand behaviour (Jorgenson and Slesnick, 1984; Varian, 1984). Due to this increase in ecological footprint, the world is confronting climate change and global warming issues (https://climate.nasa.gov/). Resource utilisation is increasing the climate change scenario worldwide (Atsu and Adams, 2021). The self-correcting mechanism of consumption in EKC is based on society's culture which contains the individuals' knowledge, beliefs, arts, laws, customs, capabilities, and habits (Benedict, 2019). If these characteristics of a society are improved and well furnished (in short, culture is enriched), it becomes helpful in downward bending the slope of EKC (Disli et al., 2016). Some elements like production efficiency (Canan and Ceyhan, 2020), demand for hygienic products (Rouf et al., 2018) and the recycling process in production (Hole and Hole, 2019) can increase the downward bending of EKC and control the ecological footprint. However, the self-sustaining mechanism is debatable. Several empirical studies have evidenced either U-shaped or rejected inverted U-shaped EKC in different sets of countries (Arshed et al., 2021). This calls for devising organised inventions (as proposed by Varian, 1984) which can be estimated using moderators in the quadratic relationship (Haans et al., 2016).

The EKC can be moderated using some indicators of a knowledge-based economy (KBE). KBE has four pillars: education and human resource, institutions, communication technology, and innovations (World Bank Institute, 2007). These indicators are essential for considering the policy aspect (Guaita Martínez et al., 2021), especially in the case of environmental deterioration (Ganda, 2019). These indicators relate to consumption to make it sustainable with economic growth and benefit the environment. Knowledge can also be observed via the economic complexity channel (Doğan et al., 2020) related to production. The mechanism channel of the KBE is straightforward in reducing carbon emissions (Bano et al., 2018; Zafar et al., 2020). Firstly, increasing education creates awareness and human capital, increasing consumption and production efficiency, and, ultimately, falling carbon emissions (Yao et al., 2019a; Yao et al., 2019b; Cordero et al., 2020). Secondly, a similar role of institutions plays in controlling environmental deterioration (Abdulqayumov et al., 2020; Bouchoucha, 2020; Sabir et al., 2020). Well-organised institutional quality has countervailing power to tackle polluted forces from both the consumption and production side. Thirdly, technology always matters; efficient and environmentally friendly technology is always a need of every economy because it helps control environmental deterioration (Jiao et al., 2018; Zhou et al., 2019). Fourthly, innovations are helpful in carbon emissions reduction (Zhang et al., 2017; Erdoğan et al., 2020; Arshed et al., 2021). Proliferation in innovations means improvement in existing technology to make it echo-efficient. In this way, innovations help in the reduction of carbon emissions.

Among other determinants of carbon emissions, energy consumption is closely related (Heravi et al., 2020) and renewable energy is vital within this framework (Chen et al., 2022). Basically, it does not deteriorate the environment by releasing carbon emissions (Cheng et al., 2019; Saidi and Omri, 2020). The increasing environmental issues and rapid increase in population are one reason and it shrinks the living area and, eventually, environmental issues emerge (Ribeiro et al., 2019; Rahman et al., 2020). Similarly, financial development measured with money supply provokes people to consume more. This causes an increase in aggregate demand and, eventually, the production process is motivated which starts to increase carbon emissions (Acheampong, 2019; Nguyen et al., 2020).

This study aims to test the existence of EKC for all the countries using standard nonlinear tests discussed by Haans et al. (2016). Moreover, this study investigates the impact of renewable energy consumption, population density, and financial development as environmental quality control factors. This study discovered the role of KBE indicators in reducing environmental deterioration. Firstly, it is hypothesised that KBE indicators can induce the self-sustaining mechanism in demand to trace EKC. Secondly, this study examines the reduction in time to achieve the cut-off value of carbon emissions due to the knowledge economy, along with moderating role of these indicators in shaping EKC and environmental betterment. Lastly, this study examines these indicators' development and country-wise role in reducing cut-off value. These findings augment the EKC relationship in reducing CO_2 emissions and open discussions for organised intervention in EKC.

After having a comprehensive introduction, this study is divided into four more sections. Section 2 reviews the literature and identifies the research gap. The data and methodology are explained in Section 3. It covers the description of the variables, estimated techniques, and models. The empirical results are discussed in Section 4. Section 5 concludes the significant findings along with policy implications.

2. Empirical literature

As environmental issues are emerging daily, literature on the subject matter is also increasing. Every study tried to bring about a unique idea. Within this frame of reference, the concept of EKC is widely tested in the literature. EKC is derived from the work of Kuznets which is part of development economics (Kuznetz, 1955). Grossman and Krueger (1991) started work on it later, followed by Selden and Song (1994) and Stern et al. (1996). After that, many studies tried to cover the subject matter. According to Kuznets Curve, economic growth at the initial stage increases income inequality. However, income inequality starts to reduce after a specific level of economic growth via the trickle-down effect (Todaro and Smith, 2015). Likewise, EKC means that the initial phase of economic growth degrades the environment but, after a specific size of economic activity, it becomes environment-friendly (Vasanth et al., 2015; Zaman et al., 2016; Wang and Liu, 2017; Dong et al., 2018; Usman et al., 2019; Altıntaş and Kassouri, 2020; Arshed et al., 2021).

In the literature on EKC, the empirical evidence is mixed regarding U and inverted U-shaped EKC. The studies and their samples are tabulated in Table 1. Table 1 enlists the studies into outcomes of Inverted U shaped, U shaped, and mixed country-wise outcomes, showing a need to settle this debate.

In the literature, different studies have chosen different control variables to define the context of their study. This study shortlists the most commonly used control variables, first, renewable energy. This type of energy consumption is helpful in carbon reduction and this phenomenon is confirmed by Dogan and Seker (2016), Lu (2017), Jin and Kim (2018), Adams and Acheampong (2019), and Saidi and Omri (2020). Several studies, such as Ibrahiem (2016), Ribeiro et al. (2019), Rahman et al. (2020), Qi et al. (2020) and Li et al. (2021), have used population density as a determinant of carbon emissions. According to these studies higher population density means higher footprints from food, resources, and economic activity provision. Financial development is directly related to carbon emissions and many studies (Acheampong, 2019; Nguyen et al., 2020; Vo and Zaman, 2020; Li et al., 2021) confirm this relationship between money supply and carbon emissions..

The mechanism of the knowledge-based economy indicators in reducing environmental deterioration works by altering the culture of demanders. For instance, technology always creates ease in peoples' lives because when people start integrating technology into production it improves quality and efficiency, gives way to modernisation, and safeguards against environmental deterioration (Jiao et al., 2018; Zhou et al., 2019). Secondly, the existence of innovations means gradual improvement in existing technology which is not only helpful in the reduction of costs but also increases competitiveness. Additionally, innovations can protect the environment (Zhang et al., 2017; Erdoğan et al., 2020; Arshed et al., 2021). The third indicator of a knowledge-based economy is education; it enriches people's understanding of themselves and the world and creates awareness among them. Education raises people's productivity and creativity and promotes entrepreneurial skills. It not only improves individuals' thinking styles but also makes them responsible citizens. In the same context, it is helpful to improve environmental quality (Yao et al., 2019a; Yao et al., 2019b; Cordero et al., 2020). Lastly, institutions are important because they are necessary for efficient knowledge and sound entrepreneurship.

This study tried to test the role of a knowledge-based economy in determining and moderating the EKC. The knowledge-based economy has four pillars (World Bank Institute, 2007) and no study in the literature has used these four pillars together in determining EKC. These pillars are available separately in different studies shown in Table 2. These proposed knowledge economy indicators are discussed in literature individually as possible means to reduce the carbon footprint from economic activities. This study also considers possible measures to promote green and responsible consumption patterns which will help bend the EKC curve faster than the unregulated and self-correcting rate. In a few instances, literature has discussed the moderating role of policy options in altering the EKC relationship. Mehmood et al. (2021) assess the negative moderating effect of institutional quality on the GDP and CO_2 emissions relationship for major South Asian countries.

Literature provides some insights into the gaps. Firstly, only a few studies have used the methodological approach to confirm the EKC relation and validate the U or inverted-U shape, as suggested by Haans et al. (2016). Secondly, there is a need for more studies exploring the demand or supply forces' motivated EKC relationship. Thirdly, only a few studies explored the moderation of the EKC relationship in reducing net CO_2 emissions (Mehmood et al., 2021; Arshed et al., 2022). This assessment will provide the means for policymakers to reduce CO_2 emissions from economic activity. Lastly, no evidence exists in the literature about the role of the four

Table 2
Role of knowledge economy in CO_2 emissions.

Knowledge Indicator	Role in CO_2 emissions	References
Technology	Resource efficiency and productivity	Shahbaz et al. (2016); Lin et al. (2017); Yang et al. (2018); Koçak and Ulucak (2019)
Innovation	Development of cleaner living and production methods	Hashmi and Alam (2019); Ganda (2019); Erdoğan et al. (2020); Khan et al. (2020); Shahbaz et al. (2020); Awan and Azam (2022)
Education	Awareness and skills to form responsible consumption	Yao et al. (2019a); Cordero et al. (2020); Molthan-Hill et al. (2020)
Institutional Quality	Regulation and accountability for a cleaner environment	Runar et al., 2017; Andersson, 2018; Nguyen et al., 2018; Khan et al., 2020; Wawrzyniak and Doryń, 2020

Table 1
Tabulation of EKC relationship outcomes in literature.

Inverted U Shaped EKC	U Shaped EKC	Mixed outcomes
Puzon and Alonzo (2012) in 8 East Asia; Du et al. (2012) in Provinces of China; Lora et al. (2013) in Towns in Colombia; Chow and Li (2014) in 132 countries; Osabuohien et al. (2014) in 50 African countries; Arbulú et al. (2015) and Altıntaş and Kassouri (2020) in 14 European countries; Azam and Khan (2016) and Sirag et al. (2018) in 143 countries in different income groups; Shahpouri et al. (2016) in 54 countries in development groups; Lorente and Álvarez-Herranz (2016) in 17 OECD countries; Atasoy (2017) in 50 states of the USA; Awan et al. (2020) in 6 MENA countries; Raza and Shah (2018) in 7 G7 countries; Shahbaz et al. (2018) in 86 countries; Koilo (2019) in 11 emerging economies; Chu (2020) in 118 countries	Dietz et al. (2012) in 58 countries; Sahli and Rejeb (2015) in 21 MENA countries; Vasanth et al. (2015) in India; Ota (2017) in 20 Asian countries; Arshed et al. (2021) in 80 countries development wise; Kilinc-Ata and Likhachev (2022) in Russia; Karahasan and Pinar (2022) in Turkish provinces; Ongan et al. (2022) in 3 NAFTA countries	Martinez-Zarzoso and Maruotti (2013) in 23 OECD countries; Ozcan (2013) in 12 Middle Eastern Countries; Beck and Joshi (2015) in 22 OECD, 22 Latin American, 11 Asian and 12 African countries' comparison; Shahbaz (2019) in the 11 countries from Next-11 group; Dogan and Inglesi-Lotz (2020) for 7 European countries; Jena et al. (2022) in selected 3 Asia's top carbon-emitting countries

pillars of the knowledge-based economy. This study has incorporated these indicators and considered them as moderators for determining the slope of EKC.

3. Data and methodology

3.1. Variables and sample

This study is based on worldwide secondary data from 2008 to 2018 (147 countries). The sample of these countries is classified based on the Human Development Index (HDI). The dependent variable is carbon dioxide (CO_2) emissions in metric tons per capita, an indicator of environmental deterioration. Sugiawan and Managi (2016), Zoundi (2017), Katircioglu et al. (2018), Yao et al. (2019a), Yao et al. (2019b), Dogan and Inglesi-Lotz (2020) and Hassan et al. (2021) have used it as a proxy for environmental deterioration. First, gross national income per capita in the constant 2010 US$ is used as a proxy of aggregate demand (AD) (as discussed by Narayan et al. (2016) and Imoudu et al. (2019)). Secondly, renewable energy consumption is a percentage of total final energy consumption (RE). Renewable energy is used in percentage form whose increase does not represent the increase in aggregate demand rather it shows the transition from fossil energy to renewable energy. This rules out the issue of multicollinearity. To capture the role of the financial sector money supply as a share of GDP is included (BM). Population density is taken as a ratio between total population and land area (PD) to see the role of population in carbon emissions. All the economic indicators are taken from World Development Indicators (WDI) and are used in natural log form to normalise variables into ratio/growth forms. On the other hand, to capture the role of a knowledge-based economy this study has utilised four indicators which are technological readiness (TE), innovations (IN), higher education and training (ED) and institutional quality (IQ). All these indicators are taken from the World Economic Forum (WEF), which is available as a national average of the index (1 for the worst and 7 for the best).

3.2. Theoretical model

This study proposes two regression models; Model 1 has three equations while Model 2 has four equations. Model 1 is developed to confirm the existence of EKC using Haans et al.'s (2016) method. The reason for separating the two equations is to assess before and after cut-off values to distinguish the existence of EKC. The regression Eqs. (2) and (3) are constructed to split the data based on the cut-off value from Eq. (1). Technically, to confirm the existence of EKC the signs of coefficients of aggregate demand in the second and third regression equation should be positive and negative respectively, and statistically significant as proposed by Haans et al. (2016).

Model 2 includes the impact of four knowledge indicators to identify their role in determining environmental quality while altering the demand-based EKC. Moreover, they influence the structure of economic incentives in society and play their role in improving environmental quality (Jiao et al., 2018; Zhou et al., 2019). In the regression models proposed below the first regression equation in Model 1 is based on the overall sample where β_0 is the intercept term. At the same time, β_1 and β_2 are the coefficients of aggregate demand and its square respectively to test the existence of EKC. β_3, β_4 and β_5 are the coefficients of renewable energy, population density, and broad money control variables respectively.

Haans et al. (2016) provide the specification to add a moderator in a quadratic function. Here in Model 2 Eq. (1), β_6 is the coefficient of technology and β_7 is the coefficient of the cross-product of technology and aggregate demand (interaction effect). In the second regression equation, β_6 is the coefficient of innovation and β_7 is the coefficient of the cross-product of innovation and aggregate demand. In the third regression equation, β_6 is the coefficient of education and β_7 is the coefficient of the cross-product of education and aggregate demand. In the fourth regression equation, β_6 is the coefficient of institutional quality and β_7 is the coefficient of the cross-product of institutional quality and aggregate demand. Ultimately, e_{it} is the normally distributed error term in every regression equation.

Model 1.

1. $CO_{2it} = \beta_0 + \beta_1\ AD_{it} + \beta_2\ AD_{it}^2 + \beta_3\ RE_{it} + \beta_4\ PD_{it} + \beta_5\ BM_{it} + e_{it}$ (Overall Sample)
2. $CO_{2it} = \beta_{10} + \beta_{11}\ AD_{it} + \beta_{12}\ RE_{it} + \beta_{13}\ PD_{it} + \beta_{14}\ BM_{it} + e_{1it}$ (Before Cut-off Sample) (The cut-off value is generated from the Eq. (1).)
3. $CO_{2it} = \beta_{20} + \beta_{21}\ AD_{it} + \beta_{22}\ RE_{it} + \beta_{23}\ PD_{it} + \beta_{24}\ BM_{it} + e_{2it}$ (After Cut-off Sample)

Model 2.

1. $CO_{2it} = \beta_0 + \beta_1\ AD_{it} + \beta_2\ AD_{it}^2 + \beta_3\ RE_{it} + \beta_4\ PD_{it} + \beta_5\ BM_{it} + \beta_6\ TE_{it} + \beta_7\ AD_{it} \times TE_{it} + e_{it}$
(Role of Technology).
2. $CO_{2it} = \beta_0 + \beta_1\ AD_{it} + \beta_2\ AD_{it}^2 + \beta_3\ RE_{it} + \beta_4\ PD_{it} + \beta_5\ BM_{it} + \beta_6\ IN_{it} + \beta_7\ AD_{it} \times IN_{it} + e_{it}$ (Role of Innovations).
3. $CO_{2it} = \beta_0 + \beta_1\ AD_{it} + \beta_2\ AD_{it}^2 + \beta_3\ RE_{it} + \beta_4\ PD_{it} + \beta_5\ BM_{it} + \beta_6\ ED_{it} + \beta_7\ AD_{it} \times ED_{it} + e_{it}$
(Role of Education).
4. $CO_{2it} = \beta_0 + \beta_1\ AD_{it} + \beta_2\ AD_{it}^2 + \beta_3\ RE_{it} + \beta_4\ PD_{it} + \beta_5\ BM_{it} + \beta_6\ IQ_{it} + \beta_7\ AD_{it} \times IQ_{it} + e_{it}$
(Role of Institutional Quality).

To understand this model theoretically, Fig. 1 is presented. It shows an inverted U-shaped curve. It is the EKC framework together with introducing moderation terms to the quadratic relationship. These moderators are technology, innovations, education, and institutional quality and these factors of a knowledge-based economy are considered environmental quality improvers by shifting the cut-off/turning point.

This study has proposed several hypotheses which are provided here. To confirm the existence of EKC, aggregate demand, commonly known as gross national income, is taken along with its square form. Several studies have tested this type of EKC (Miglietta et al., 2017; Moosa, 2017; Destek and Sarkodie, 2019; Zhang et al., 2019; Sinha et al., 2020). It is hypothesized that aggregate demand and its square follow an inverted U-shaped relationship with carbon emissions where the increasing/positive effect of aggregate demand of CO_2 (deterioration stage) is tested in H_1 and the downward bending/negative effect of aggregate demand squared on CO_2 (maturity stage) is tested in H_2 (Haans et al. (2016) have provided a detailed mechanism to test the hypothesis for curvilinear relationships. The significance of H_1 alone will signify a linear relationship. Moreover, positive H_1 and negative H_2 will confirm the inverted U-shaped effect of aggregate demand on CO_2.).

This study includes the renewable energy used by several studies (Dogan and Seker, 2016; Lu, 2017; Jin and Kim, 2018; Adams and Acheampong, 2019; Saidi and Omri, 2020). It is hypothesized that higher usage of renewable energy decreases carbon emissions (H_3). This study also includes population density. Several studies have used it (Ibrahiem, 2016; Ribeiro et al., 2019; Qi et al., 2020; Rahman et al., 2020; Li et al., 2021) which is why it is used as a controlling variable. It is hypothesized that population density increases carbon emissions (H_4). This study also incorporated the financial sector for which money supply is a controlling factor (H_5) and is also used by several studies (Ali et al., 2016; Acheampong, 2019; Nguyen et al., 2020; Vo and Zaman, 2020).

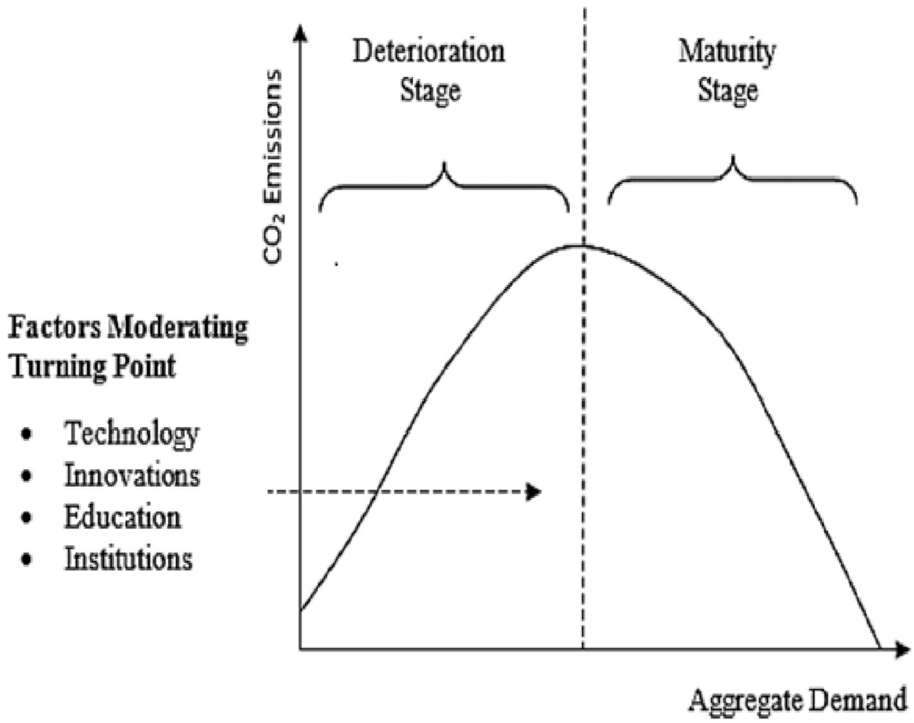

Fig. 1. Theoretical model.

This study has also included the four pillars of a knowledge-based economy: education and human resource, institutions, communication technology, and innovations. When the role of technology and innovations is included in the EKC framework it is known as STIRPAT. As the STIRPAT means stochastic (ST) impacts (I) by regression (R) by population (P), Income per capita or affluence (A), and technology (T). In the first and second regression equation of Model 2, the role of technology and innovations is incorporated which is why it is the STIRPAT framework. Several studies have used the role of technology (Shahbaz et al., 2016; Lin et al., 2017; Yang et al., 2018; Koçak and Ulucak, 2019). It is hypothesized that technology can prove helpful in reducing carbon emissions (H_6) and moderating CO_2 emissions for each level of aggregate demand (H_{6a}). Several studies have used innovations (Hashmi and Alam, 2019; Ganda, 2019; Erdoğan et al., 2020; Khan et al., 2020; Shahbaz et al., 2020). It is hypothesized that innovations can prove helpful in reducing carbon emissions (H_7) and moderating CO_2 emissions for each level of aggregate demand (H_{7a}). This study also includes the role of education which several studies have used (Yao et al., 2019a; Cordero et al., 2020; Molthan-Hill et al., 2020). It is hypothesized that education can prove helpful in reducing carbon emissions (H_8) and moderating CO_2 emissions for each level of aggregate demand (H_{8a}). The fourth pillar that is being used in this study is institution quality. In the literature, there are several studies which have confirmed the relationship between institution quality with carbon emissions (Runar et al., 2017; Andersson, 2018; Nguyen et al., 2018; Khan et al., 2020; Wawrzyniak and Doryń, 2020). It is hypothesized that institutional quality can prove helpful in reducing carbon emissions (H_9) and moderating CO_2 emissions for each level of aggregate demand (H_{9a}). Hence, the following are the alternative hypotheses set by this study:

H_1: An increase in aggregate demand increases CO_2 emissions below the threshold.
H_2: An increase in aggregate demand reduces CO_2 emissions beyond the threshold.
H_3: Higher use of renewable energy decreases CO_2 emissions.
H_4: An increase in population density increases CO_2 emissions.
H_5: Financial sector development affects CO_2 emissions.
H_6: Higher technological readiness affects CO_2 emissions.
H_{6a}: Higher technological readiness moderates to reduce CO_2 emissions associated with aggregate demand increase.
H_7: Increase in innovations affects CO_2 emissions.
H_{7a}: Increase in innovations moderates the CO_2 emissions associated with aggregate demand increase.
H_8: Higher education affects CO_2 emissions.
H_{8a}: Higher education moderates the CO_2 emissions associated with aggregate demand increase.
H_9: Improvement in institutional quality affects CO_2 emissions.
H_{9a}: Improvement in institutional quality moderates the CO_2 emissions associated with aggregate demand increase.

3.3. Estimation technique

The results are estimated with the help of the panel Fully Modified Ordinary Least Square Method (FMOLS). It is a semi-parametric correction for the variance–covariance matrix to remove the issues related to time series correlation and random differences of cross-sections (Phillips and Hansen, 1990; Pedroni, 2001; Global, 2014, 2015; Iqbal et al., 2021). Further, since the years per cross-section are less than 19, the data sets can be assumed stationary (Arshed et al., 2018) because of low power of panel unit root tests. The moderation effects are plotted using the Dawson (2014) method and the average total effects on the world map are plotted using R studio.

FMOLS was introduced by Phillips and Hansen (1990) which helps estimate asymptotically unbiased and efficient long-run relations by employing a semi-parametric correction to the residuals.

Consider the following long-run equation.

$$Y_t = \alpha_1 X_{1t} + u_{1t}$$

The estimation of correction factor u_{2t} starts from the estimation of the following equation of independent variables using deterministic factors (D).

$$X_t = \beta_1 D_{1t} + \beta_2 D_{2t} + e_{2t}$$

$$\Delta e_{2t} = u_{2t}$$

The data is modified using the following equation: Ω is the covariance matrix of squared residuals u_t^2.

$$Y_t^+ = Y_t - w_{12}\Omega_{22}^{-1}u_2$$

And the estimated bias corrected is done using

$$\lambda_t^+ = \lambda_t - w_{12}\Omega_{22}^{-1}u_2$$

The FMOLS estimates are generated using

$$\hat{\theta} = \begin{bmatrix} \alpha \\ \hat{\gamma}_1 \end{bmatrix} = \left(\sum_{t=2}^{T} Z_t Z_t'\right)^{-1} \left(\sum_{t=2}^{T} Z_t Y_t^+ - T\begin{bmatrix} \lambda_t^+ \\ 0 \end{bmatrix}\right)$$

where, Z_t is the vector of the independent variables. Studies like Dogan and Aslan (2017), Bahri et al. (2018) and Jamil et al. (2022) have used FMOLS with group mean specification for the case of variables which are non-stationary and have cross-section dependence. For the stationary data sets, this study has several options available for estimations within which the FMOLS model is selected because its residuals are free of cross-sectional dependence, autocorrelation, and heteroskedasticity.

4. Results and discussion

Table 3 contains descriptive statistics of all the variables. Firstly, the mean and standard deviations are compared. When the mean is bigger the data are under-dispersed and when the mean is smaller the data are over dispersed. Here, CO_2 is over dispersed while all other variables are under-dispersed. Further, based on the Jaque Bera test, all variables are statistically non-normal. Since the data is more than 30 observations the data is assumed to be asymptotically normal (De Muth, 2014).

The estimated results are presented in Tables 4 and 5. These results are estimated using FMOLS. The aggregate demand and its square show positive and negative signs which means it follows an inverted U-shaped relationship. Therefore, aggregate demand has an inverted U-shaped relationship with carbon emissions. Similar findings have been found in the studies by Sirag et al. (2018), Kong and Khan (2019), Alsamara et al. (2018), and Altıntaş and Kassouri (2020). Control variables significantly affect carbon emissions as reported in the overall sample results. The negative sign of renewable energy consumption means that it has the potential to reduce carbon. Similar findings have been found in the studies by Lu (2017), Jin and Kim (2018), Cheng et al. (2019), and Saidi and Omri (2020). The population is another critical factor in environmental quality and the positive coefficient of population density means the environment is deteriorating due to worldwide carbon emissions. Similar findings have been found in the studies by Ribeiro et al. (2019), Rahman et al. (2020), Qi et al. (2020) and Li et al. (2021). Financial development in the form of money supply has a positive coefficient which means it is increasing carbon emissions. Similar findings have been found in the studies by Acheampong (2019) and Nguyen et al. (2020). An increase in money supply increases the purchasing power of the consumers which causes an increase in aggregate demand and, in turn, an increase in the production process leading to an increase in carbon emissions.

Table 4 also contains regression results of before and after cut-off samples for checking the existence of EKC. From this point, the data is divided into two parts, cut-off. As the cut-off value is 9.360 it means that, with the increase in aggregate demand, the environment gets polluted, however, when aggregate demand reaches 9.360 it is at a peak point. Beyond the 9.360, any increase in aggregate demand shows there is no environmental deterioration. The noticeable thing is that the cut-off value is higher than the average value of carbon emissions which is alarming. This value lies between the ranges of this aggregate demand (as shown in Table 3). The results below the cut-off are similar overall but after the cut-off sample the results are statistically insignificant. This concludes that demand alone does not have the ability to transition toward sustainability.

Further quadratic fit is shown in Fig. 2 showing the nonlinear pattern of aggregate demand (Dawson, 2014) which is inverted U-shaped. The overall conclusion is still the same (because the previously estimated results are insignificant) that the existence of EKC is not confirmed in this study as an individual relation. However, this study has extended the relation and added the moderating effect of knowledge economy indicators. Here, moderation ensures cultural transformation as the knowledge economy plays a role in transforming consumption patterns to reduce CO_2 emissions.

Table 5 contains the estimated results of Model 2. The estimated results regarding aggregate demand, its square, and the control variables are the same as in Table 4. In the case of technology as a knowledge economy indicator it is increasing carbon emissions. Similar findings have been found in the studies by Ganda (2019) and Arshed et al. (2021). The noticeable thing is that even though the technology is increasing carbon emissions its cross-product with aggregate demand reduces carbon emissions. Thus, consumption expenditures involving improved technological goods are helpful for environmental protection. Discussing innovations as a second indicator of the knowledge economy, they are reducing carbon emissions as its coefficient is similar to negative findings that have been found in the studies by Ganda (2019), Khan et al. (2020), and Shahbaz et al. (2020). However, the cross-product of innovations with aggregate demand is positive but less than the coefficient of aggregate demand. So, innovative goods and services are less harmful than non-innovative ones. It means that more innovations improve the environment directly. However, the cross-product coefficient of innovations and aggregate demand is less than that of aggregate demand, thereby slowing down the decrease in the CO_2 stage. Higher education is the third knowledge

Table 3
Descriptive statistics.

	CO_2	AD	RE	BM	PD	IN	TE	ED	IQ
Mean	0.619	8.395	2.862	3.928	4.260	3.262	3.566	3.889	4.062
Median	0.811	8.390	3.341	3.932	4.351	3.085	3.362	3.891	3.850
Maximum	3.585	11.445	4.573	5.901	8.962	5.838	6.287	6.093	6.186
Minimum	−3.785	5.429	−5.119	2.390	0.560	2.009	2.027	1.899	2.094
Std. Dev.	1.469	1.346	1.683	0.620	1.433	0.799	1.000	0.934	0.889
JB Test	42.814	19.120	1721.881	54.542	17.990	295.303	131.135	13.762	107.006
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4
FMOLS estimations for Model 1.

Dependent variable – CO_2						
	Overall sample		Before cut-off sample		After cut-off sample	
Variables	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
AD	3.673	0.000	0.548	0.000	−0.007	0.933
AD^2	−0.196	0.000				
RE	−0.214	0.000	−0.300	0.000	−0.098	0.000
PD	0.494	0.000	0.661	0.000	−0.369	0.008
BM	0.032	0.001	0.060	0.009	−0.041	0.326
Cut-off value	9.360					
R^2	0.995		0.993		0.983	

Table 5
FMOLS estimations for Model 2.

Dependent variable – CO_2								
	Technology		Innovations		Education		Institutions	
Variables	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value
AD	1.834	0.000	2.107	0.000	3.191	0.000	2.273	0.002
AD^2	−0.095	0.000	−0.120	0.000	−0.199	0.000	−0.153	0.000
RE	−0.201	0.000	−0.249	0.000	−0.207	0.000	−0.143	0.003
PD	1.042	0.000	1.068	0.000	0.894	0.000	0.891	0.000
BM	0.264	0.000	0.280	0.000	0.210	0.000	0.297	0.001
TE	0.201	0.000						
IN			−0.207	0.000				
ED					−0.829	0.000		
IQ							−0.745	0.001
AD*TE	−0.024	0.000						
AD*IN			0.015	0.000				
AD*ED					0.088	0.000		
AD*IQ							0.092	0.000
Cut-off value	9.219		8.922		8.941		7.248	
R^2	0.996		0.995		0.995		0.996	

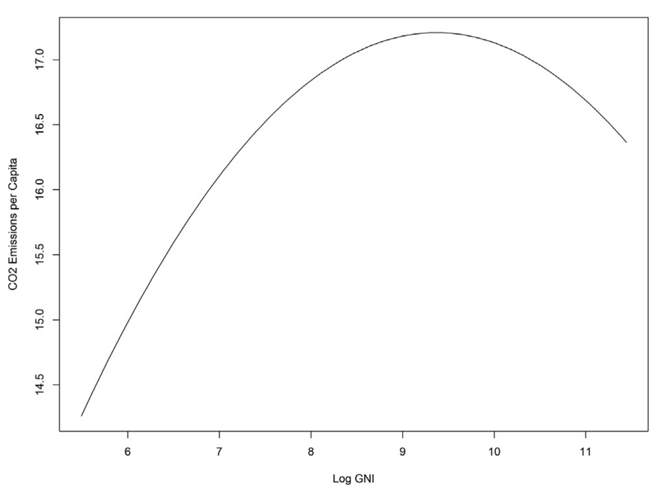

Fig. 2. Aggregate demand-based EKC.

economy indicator and the negative coefficient indicates that more education creates more awareness that reduces carbon emissions. Similar findings have been found by Yao et al. (2019a), Cordero et al. (2020), and Molthan-Hill et al. (2020).

Further, the cross-product coefficient of higher education and aggregate demand is also less than that of aggregate demand. It means that more education changes the demand pattern of consumers but it also increases demand pressure because of an increase in skilled worker incomes. Institutional quality is studied as the fourth indicator of the knowledge economy and the negative coefficient means improved institutional quality is advantageous for reducing carbon emissions. Similar findings have been found by Ibrahim and Law (2016), Sarkodie and Adams (2018), Acheampong et al. (2019), Adams and Acheampong (2019), Khan et al. (2020), Muhammad and Long (2021), Mehmood et al. (2021), and Haldar and Sethi (2020). However, the cross-product of institutional quality with aggregate demand is indicating strong institutional quality provokes such a consumption level which deteriorates the environment by emitting carbon dioxide. Nevertheless, the cross-product coefficient of institutional quality and aggregate demand is less than that of aggregate demand. These results oppose the outcomes of Mehmood et al. (2021). Table 5 also contains the cut-off values which are 9.219, 8.941, 8.922 and 7.248 for the first, second, third and fourth regression equations of Model 2 respectively. It means that after the cut-off values under each knowledge economy intervention are calculated at average, an increase in aggregate demand (respective to the concern regression equation) would reduce CO_2 emissions. These cut-off values are smaller than the overall of 9.360 which means that knowledge economy intervention can reduce the net CO_2 produced from demand activities. Since all of the included variables are significant at a 1% level all of the study's alternative hypotheses are accepted and mentioned in Table 6.

The role of knowledge indicators as moderators of EKC is highlighted using the quadratic fit. Figs. 3 to 6 are constructed to test the nonlinear pattern of aggregate demand using interpreting interaction effects (Dawson, 2014). Fig. 3 shows the role of technology and environmental quality and it describes how technological advancement firstly increases carbon emission but later reduces CO_2 faster. In Fig. 4, innovations have completely shifted down the EKC which means that at all levels of aggregate demand there is a fall in CO_2 emissions. Fig. 5 is about the role of education and

Table 6
Decisions for developed hypotheses.

Alternative hypotheses	Independent variables	Dependent variables	P value[1]	Decision criteria	Explanation[2]
H_1	AD	CO_2	0.00	1%	Aggregate demand does increase CO_2 below a certain threshold
H_2	AD^2		0.00		Aggregate demand does decrease CO_2 beyond a certain threshold
H_3	RE		0.00		Renewable energy reduces CO_2 emissions
H_4	PD		0.00		Population density increases CO_2 emissions
H_5	BM		0.00		Financial sector increases CO_2 emissions
H_6	TE		0.00		Technology readiness increases CO_2 emissions
H_{6a}	TE*AD		0.00		Technology readiness positively moderates aggregate demand and CO_2 relationship
H_7	IN		0.00		Innovations reduce CO_2 emissions
H_{7a}	IN*AD		0.00		Innovations negatively moderates aggregate demand and CO_2 relationship
H_8	ED		0.00		Higher education reduces CO_2 emissions
H_{8a}	ED*AD		0.00		Higher education negatively moderates aggregate demand and the CO_2 relationship
H_9	IQ		0.00		Institutional quality reduces CO_2 emissions
H_{9a}	IQ*AD		0.00		Institutional quality negatively moderates aggregate demand and the CO_2 relationship

[1]Probability to reject alternative hypothesis. Extracted from the estimation results of respective independent and dependent variable pair in Table 5.
[2]The first two hypotheses (H_1 & H_2) are repeated in four models since the alternative is accepted in all cases so the explanation is identical for all.

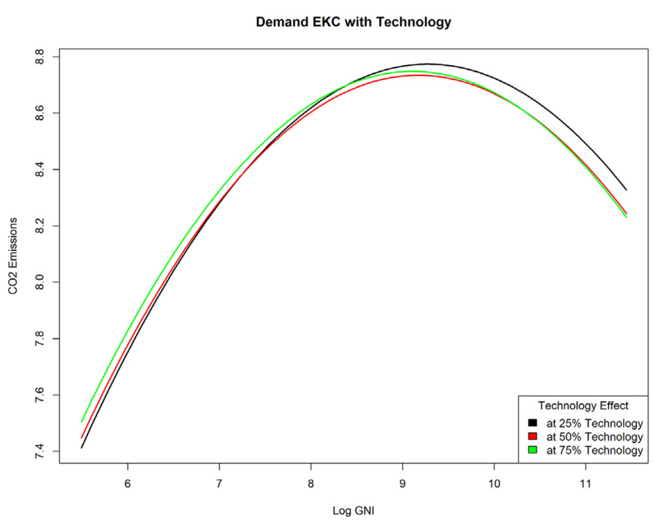

Fig. 3. EKC with technology.

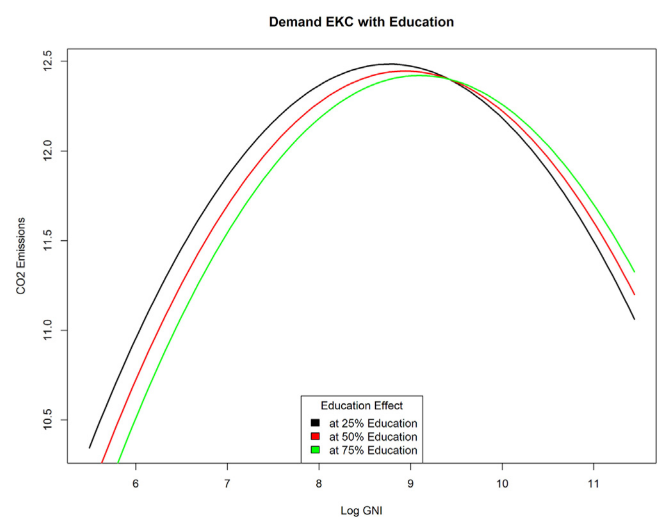

Fig. 5. EKC with education.

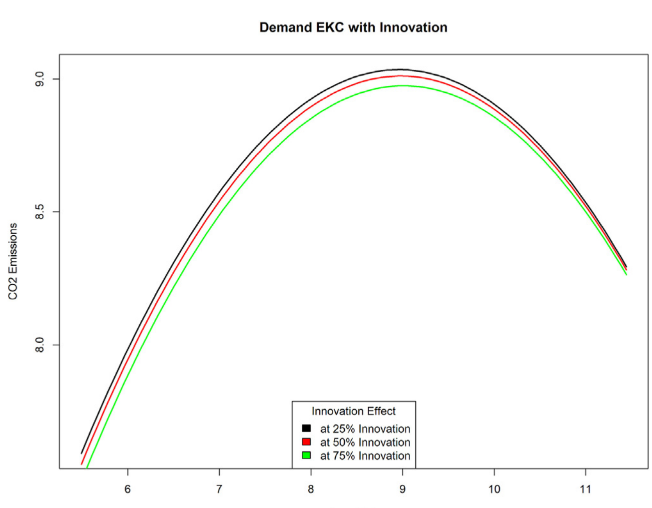

Fig. 4. EKC with innovations.

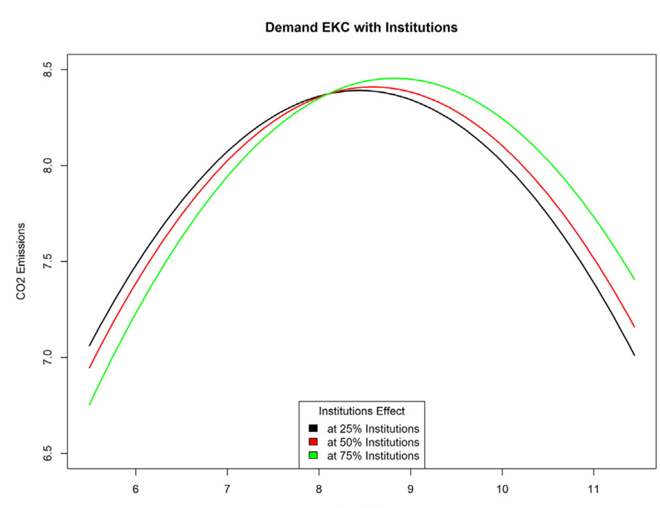

Fig. 6. EKC with institutions.

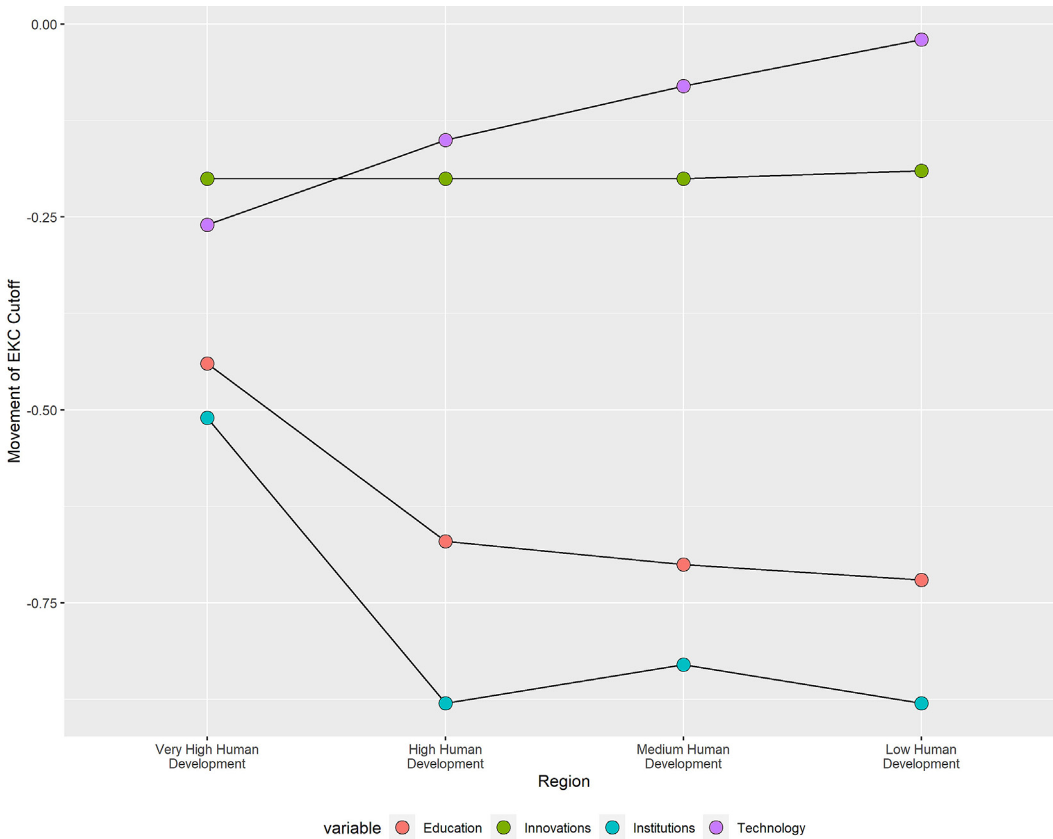

Fig. 7. Aggregate demand and development-wise policy mix.

environmental quality and it describes how educational advancement firstly decreases carbon emissions but increases them slightly later. Overall, there is a rightward shift of EKC but it is a considerable fall in CO_2 emissions at pre-cut-off stage. Fig. 6 is about institutions and environmental quality. Here institutional advancement decreases carbon emissions pre-cut-off and increases them post-cut-off (Fig. 7).

Furthermore, development-wise cut-off values with and without the presence of knowledge economy-based indicators are presented in Table 7, and country-wise cut-off values with and without knowledge economy-based indicators are presented in Supplementary Data Table 1. In Table 7, the cut-off values are calculated based on the average knowledge economy indicators in each development group. Table 7 also contains gains from each indicator to analyse the before and after effects of knowledge-based economy indicators, and the negative value of each gain indicates that these indicators are useful in reducing carbon emissions. Fig. 8 presents the role of knowledge indicators in development-wise country groups. It demonstrates the difference between overall and development-wise cut-off values. Hence, the negative values indicate the gain from the knowledge economy. Here, high and low-development country groups are the dominant and equivalent gainers from institutional quality. Education has a leading role in reducing carbon emissions in low-development countries and innovations have almost the same role to play in all these groups in reducing carbon emissions. Lastly, a very high development country group is the dominant benefice-holder from technology. Figs. 9 to 12 provide world maps to present the country-wise gains from knowledge economy indicators. Therefore, the role of technology is presented using a world map in Fig. 9. Here, the regions where the highlighted colour is dark are those where technology has a higher contribution to cleaning the environment. Here the significant gainers are North America, Europe, and Australia.

Fig. 10 contains a world map highlighting suitable regions for gains from innovations. This graph points to the role of North America, Europe, and Australia which are beneficiaries of the innovations regarding carbon emissions reduction. Fig. 11 presents the gains from education on the map. Africa and North America are the highest gainers from education in the EKC framework. The fourth pillar, institutional quality, is presented in Fig. 11. This world map indicates that Asia, Europe, Africa, and South America are the beneficiaries of institutional quality in reducing carbon emissions.

5. Conclusion and policy implications

Pursuing an economic growth strategy has its own perils. Economic activities must address the present as well as future needs of society. The unregulated growth in significant parts of the world with rampant CO_2 emissions is causing irreparable environmental damage. Empirical studies have explored the EKC relationship of GDP with CO_2 emissions but it has also faced criticism for not achieving self-sustainability. This study targets the demand-based EKC and opts for a Keynesian approach to reduce CO_2 emissions by regulating demand. Hence, this study aims to explore demand based EKC and the role of the knowledge economy as a possible intervention mechanism to induce cleaner and responsible consumption leading to a downward bending portion of EKC. Using Haans et al.'s (2016) method, although EKC is a visually inverted U shaped, this study concluded that demand does not have a self-sustaining ability in the selected countries.

This study found the significant impact of control variables, as suggested by the literature and within this controlling framework,

Table 7
Development wise cut-off values.

Policy specification	Very high HDI	High HDI	Medium HDI	Low HDI
Average of AD	10.14	8.54	7.35	6.75
Average of ED	5.03	4.03	3.32	2.74
Average of IN	4.08	3.06	2.91	2.84
Average of TE	5.00	3.52	2.93	2.64
Average of IQ	3.66	3.49	3.52	4.73
No policy	9.36	9.36	9.36	9.36
TE policy	9.10	9.21	9.28	9.34
ED policy	8.92	8.69	8.66	8.65
IN policy	9.16	9.16	9.17	9.17
IQ policy	8.53	8.48	8.49	8.85
Gain from TE	−0.26	−0.15	−0.08	−0.02
Gain from ED	−0.44	−0.67	−0.70	−0.72
Gain from IN	−0.20	−0.20	−0.20	−0.19
Gains from IQ	−0.51	−0.88	−0.83	−0.88

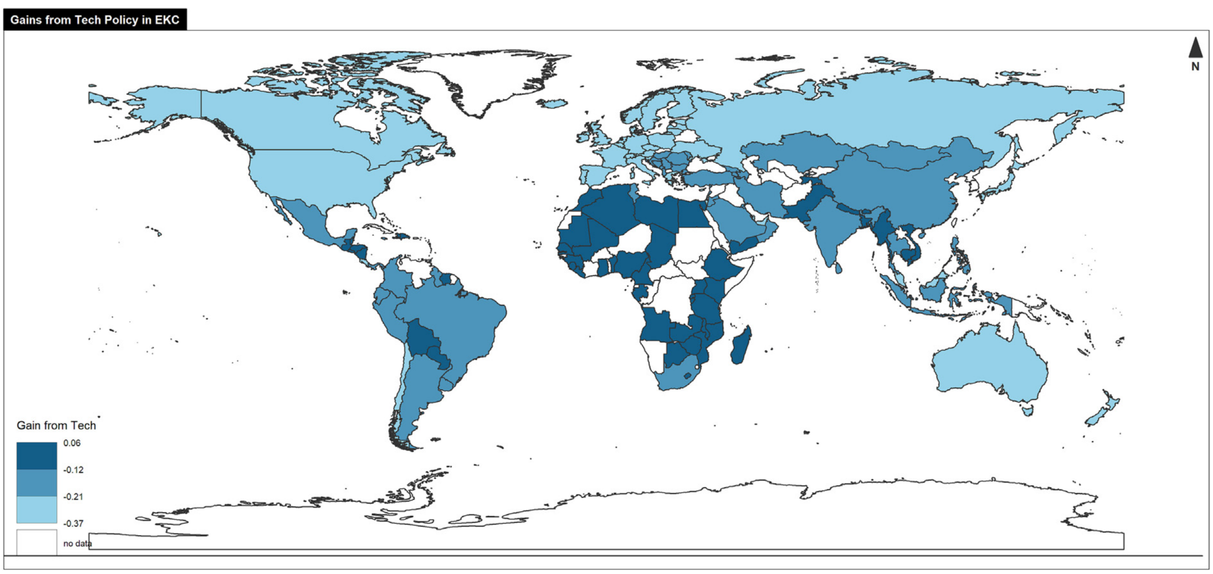

Fig. 8. Gains from technology policy in EKC.

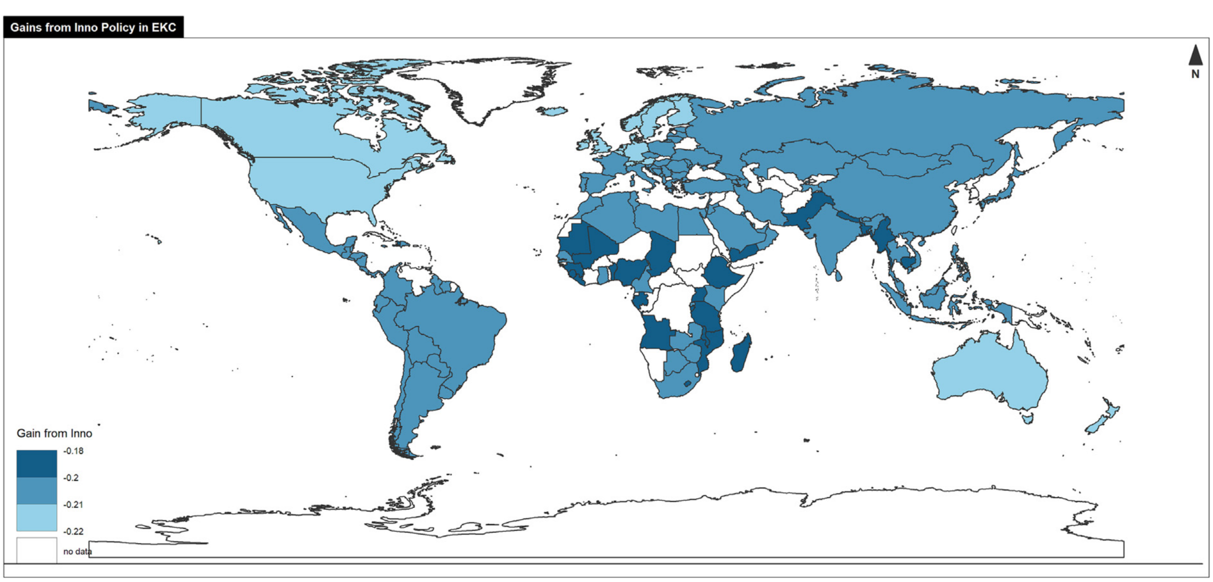

Fig. 9. Gains from innovations policy in EKC.

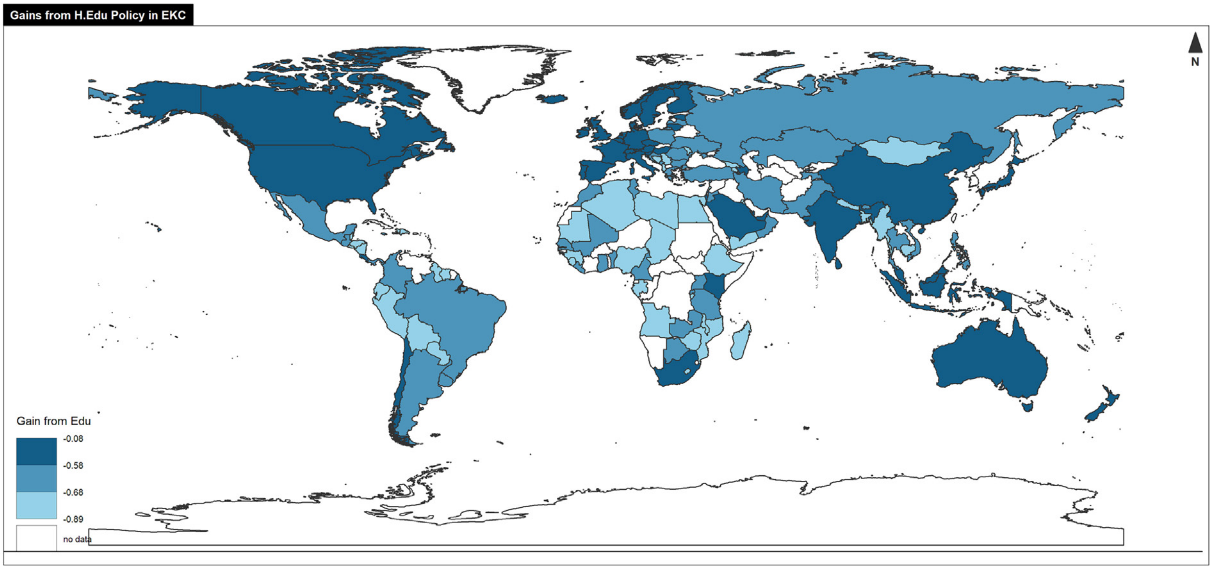

Fig. 10. Gains from education policy in EKC.

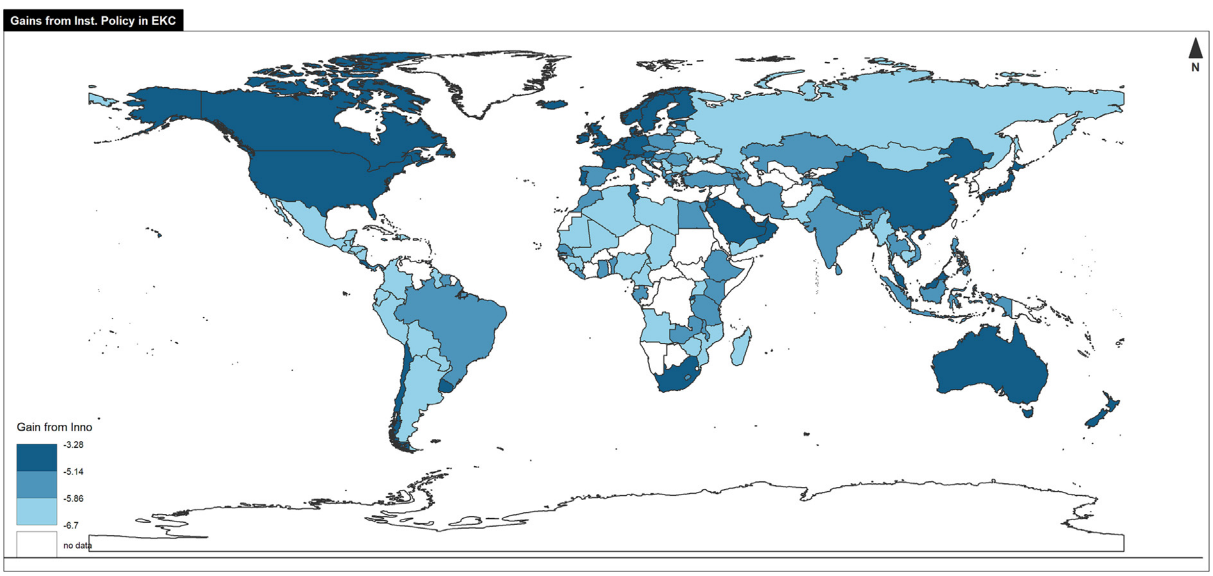

Fig. 11. Gains from institutions policy in EKC.

means EKC does not hold. The invalidation of EKC in isolation points to the self-correcting culture being insufficient to bend the EKC downward at higher levels of aggregate demand. This study has proposed knowledge economy indicators as a possible intervention to initiate responsible and clean consumption patterns to reduce CO_2 emissions from demand. The results presented by this study confirmed that an increase in the knowledge economy helps in reducing the cut-off value of EKC which represents the net decrease in CO_2 emissions. This was also highlighted in Figs. 9 to 11.

The four pillars of the knowledge-based economy have fascinating empirical results. The negative coefficient of innovations, education, and institutional quality means these indicators are responsible for decreasing carbon emissions. However, technology is responsible for increasing carbon emissions which is due to the use of proxy of technology and its implementation restrictions (Awan and Azam, 2022). Furthermore, the interaction term of these four KBE pillars with aggregate demand is being used. Here, technology, education, and innovations are moderating the slope of EKC downwards and reducing CO_2 emissions at all levels of aggregate demand. Similarly, education and institutional quality are responsible for increasing carbon emissions after the cut-off point. This hints at the irrelevancy of education curriculum and sub-optimality of institutions.

This study urges policymakers to instil national policy for developing a knowledge economy. Increasing knowledgeable consumers can help reduce the footprint arising from increased demands. The economy's technology and innovation can help develop cleaner methods of producing goods and energy, leading to a prominent decrease in carbon release in atmosphere. Policymakers need to include carbon/climate literacy in education curriculum and restructure the institutions which can help the individuals become climate responsible for achieving environmental sustainability.

Future studies can also help estimate the time required and cost incurred to reduce 1% of the cut-off value from each knowledge economy indicator. It can help in optimising the national policy to improve environmental quality. The results of the study are limited to the availability of data. The carbon footprint associated with different types of consumption practices is not explored in this study; instead, a knowledge-based change in consumption practices is observed with an overall fall in the footprint of consumption in the economy. Future studies can use the new data on activity-based CO_2 emissions by IPCC which can help strengthen the link between the knowledge economy and environmental quality.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gsf.2023.101594.

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