Green Growth and Sustainable Development: Dynamic linkage between Technological Innovation, ISO 14001, and Environmental Challenges

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Abstract

Over the last two decades, the phenomenon of green growth has gained much attention from academics and policymakers striving to find a sustainable solution to environmental problems worldwide. Technological innovation serves as a tool to abate the acute environmental crisis and continuously promote sustainable development by converting traditional economies into green economies. Pakistan is amongst the developing countries relying on conventional technology and energy resources to meet population and economy demands, which has led to a surge in greenhouse gases and other hazardous air pollutants. The literature exploring green growth in the Pakistani context is scant; the present study will therefore fill this gap and explore the dynamic linkage between technological innovation and ISO 14001 with green growth in Pakistan in the presence of environmental challenges such as energy consumption and population growth. A novel Grey Relational Analysis model approach is employed to examine the interrelationship between the study parameters. Results indicate that technological innovation is significantly correlated with green growth, and ISO 14001 also shows a substantial relationship with green growth. However, among the environmental challenges, energy consumption poses a barrier to green growth development as the country's energy mix is dominated by fossil fuels as compared to renewables. The research findings produce a much-needed policy suggestion to address the environmental challenges by promoting green growth development in Pakistan.

***Keywords**:* Green growth; Sustainable Development; Technological innovation; ISO 14001; Environmental Challenges

1. Introduction

Since the industrial revolution, the choice of energy sources to spur economic growth has been criticized. The resulting ecological crisis has made it one of humanity's most pressing challenges in the 21st century. The excessive use of fossil fuels to meet economic and social needs has resulted in surging emissions of CO_2 and other Greenhouse gases (GHGs). The dramatic change in

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environmental conditions is a daunting concern for all academics and policymakers worldwide, who are looking for an optimal solution to the mentioned crisis.

In 2005, the United Nations proposed green growth as the ultimate solution to achieve sustainable development. The Organization for Economic Cooperation Development (OECD) defines green growth as a new means of fostering development and economic growth in a country while causing no harmful impact on the environment or people living in it (Merino et al., 2020; Wang et al., 2020). Green growth has drawn the attention of the masses around the world, and a plethora of research has been conducted to understand the concept of green growth in different countries across the globe (Bagheri et al., 2018; Stoknes & Rockström, 2018; Wang & Shao, 2019). Green growth provides a solution to the environmental crisis and helps achieve sustainable economic growth while flourishing the interests of the population (Barbier, 2016). Green growth promotes cleaner energy sources and reduces environmental pollution by lowering the emission of CO_2 and other GHGs (Sandberg, Klockars, & Wilén, 2019). Several authors have argued about multiple determinants of green growth, but have agreed on all factors that help develop and sustain economic, environmental, and social interests (Hao et al., 2021; Mensah et al., 2018).

The industrial revolution brought tremendous changes in the way of doing things. To date, most developing countries have relied on traditional energy sources to meet national demands, resulting in serious environmental issues (Tugcu et al., 2012). Energy production from fossil fuels is a dominant factor in escalating CO_2 emissions globally (Köne & Büke, 2010). CO_2 and GHG emissions are the by-products of energy combustion from conventional energy sources like coal, gas, and oil (Wang et al., 2020). These emissions threaten human lives (Alam et al., 2011; Osobajo et al., 2020). Therefore, reducing carbon emission to abate global environmental catastrophes has become a significant concern worldwide (Acosta et al., 2020).

Technological innovation is a tool to address environmental challenges, reduce the potential climate change threats posed to human lives, and sustain economic interests (Li & Long, 2020). Technological innovations have played a crucial role in transitioning society from a traditional economy to a green one. Technological innovation supports green energy production so as to channel the development of green growth and help transform technological practices in operations and production processes within organizations (Aghion et al., 2013; Umar et al., 2020). According to Song et al. (2019), transformative technology innovation helps meet national energy demands by promoting cleaner technologies that reduce CO_2 and other harmful emissions. Wang et al. (2021) suggested that technological innovation acts as a catalyst to boost green growth. In addition to technological innovation, some organizational innovations, such as Environmental Management Systems (EMS), can help firms reduce the impact of their production. EMS is one of the widely adapted environmental sustainability tools that help public or private organizations engage in systematic processes to tackle and solve environmental issues and lower harmful impacts (Coccia & Watts, 2020; Rusko et al., 2014). The research conducted by Kammerer (2009) reveals that green practices (drawn from EMS) and innovations within an organization share a positive relationship. Prior studies have shown that EMS promotes environmental sustainability and performance by involving managers in the process (Aravind, 2012; Mungai et al., 2020).

Pakistan is a developing country, and despite having potential for renewables, its government has relied heavily on fossil fuels and traditional technological methods to meet its economic and social needs (Hussain et al., 2019). The International Energy Agency (IEA) rated Pakistan as the fifth most vulnerable country to environmental issues (International Energy Agency (IEA), 2018). Shahzad et al. (2017) found that the dependence on scarce energy resources will have a prolonged impact on the country's environment and human lives. Substantial CO_2

emissions have posed a tremendous environmental challenge for Pakistan, imposing considerable threats to the environment. While PM 2.5 (Particulate matter) is the most dangerous particulate matter in the air, drastically impacting human lives, it is a by-product of fossil fuels released from power plants and vehicles. PM 2.5 is a heavy air pollutant responsible for severe lung and heart conditions (Wu, 2017). According to the World Health Organization (WHO), more than 40 million cases and 28,000 deaths due to severe lung and respiratory diseases are reported annually in Pakistan (Environmental health, 2020). Abid et al. (2020) argued that in recent years, conventional energy consumption and population growth have caused several environmental problems, and under Belt and Road energy projects, Pakistan would produce 67% of its energy from fossil fuels like coal, gas, and oil. If technology, process, and manufacturing all remain the same, the region will face significant environmental disasters. The industrial sector in Pakistan relies on energy from fossil fuels and has become the second significant contributor to GHG emissions in Pakistan (Shrestha, 2013). The roots of the environmental problem cannot be traced to energy choices in Pakistan, as Naqvi and Rehm (2014) found that with every 1% increase in population, energy consumption and emissions would increase by 0.46% in the country.

In the light of the above, building upon secondary data collected in Pakistan and an extensive literature review, this study aims to answer a key research question: Do technological innovation and EMS adaption help the development of green growth in Pakistan?

Research concerning technological innovation and green growth is scarce (Popp, 2012). In the literature, the phenomenon of green growth has not been widely explored in the Pakistani context. Therefore, this is one of the most significant contributions in the field as Pakistan is a rapidly developing country that relies heavily on fossil fuels to meet its demands to spur economic growth (Abid et al., 2020). This study fills the gap in the literature and provides a direction for future studies revolving around green growth development in the country, and offers policy implications related to green growth for designing relevant policies that shape the future of sustainable development for the country. This study extends its contribution to the literature by examining the integrated effect of technological innovation with the development of green growth in Pakistan.

Furthermore, this study proposes a more comprehensive framework by combining technological innovation and EMS (organizational innovation) with two environmental challenges (i.e., energy consumption and population growth). To do so, the data of technological innovation (R&D, patent applications), EMS (Organizational Innovation), and green growth (CO_2 emissions, renewable energy, GHGs, and PM 2.5) from 2000 to 2019 are used. This study employs the novel GRA model approach, offering consistent, unbiased solutions as this technique offers optimal results even with a small data sample and, as a result, identifies the most effective element to promote green growth in Pakistan. The main advantage of GRA models is to ensure accuracy and superiority over statistical models (Ikram et al., 2020). Lastly, this study can be generalizable to economies having similar economic and social contexts.

The rest of the paper is structured as follows. Section 2 presents the extensive literature on technological innovation, EMS, and green growth. Section 3 describes data information and the steps involved in the construction of GRA models. Section 4 provides the results and discussion. The conclusion, policy implications, and future directions are presented in the last section of the study.

2. Literature review

2.1 Technological innovation and green growth

For over a century, increased resource consumption (fossil fuels, water, forests) has spurred growth. Rapid economic developments and increased human activities have been fueling environmental problems for decades leading to ecological catastrophes (droughts, hurricanes, and global temperature rise) that are not limited to national boundaries (Kunapatarawong & Martínez-Ros, 2016; Tseng et al., 2013). Among many, the most pressing environmental challenges are increasing CO_2 emissions, which are a byproduct of the overuse of non-renewable energy production sources. Non-renewable energy sources are scarce, and economies have been utilizing these resources for years, which has accelerated the growth process but adversely affected the environment (Du et al., 2020). Environmental challenges have a detrimental impact on human health, and continued degradation will jeopardize long-term economic goals. (Xu et al., 2021). Development at the expense of the environment has alarmed global leaders who are now striving to find a sustainable solution to tackle the environmental crisis worldwide (Cuerva et al., 2014; Li et al., 2020).

In 2005, the United Nations proposed green growth as a means to achieve sustainable economic growth without harming the environment (Kang, 2015). Green growth promotes the nationwide pursuit of growth and development while ensuring the efficient use of natural resources to protect the environment (OECD, 2011). Therefore, the transformative characteristic of green growth has drawn global attention. “Green” represents harmony between humans and the environment, and “growth” encompasses the prosperity of a country and its people. Green growth provides an ultimate solution to the environmental challenges and accelerates the deployment of clean energy sources to reduce environmental degradation (Aguilera-Caracuel et al., 2013; Li et al., 2019a).

Scholars (Hao et al., 2021; Su et al., 2020) have recently emphasized the role of technology in promoting green growth development. However, the effect of technological innovation on green growth is much debated in the field. Technology is one of the prime factors that organizations have been using to excel in performance and constantly impact humans and the environment (Li et al., 2019b). Environmental awareness has made policymakers realize that technology intensifies environmental issues, and progress leading to environmental catastrophes is not advisable. Therefore, a shift has been observed to upgrade traditional technology to green or clean technology through resource-efficient innovation and to substantially reduce environmental pollution (Schiederig et al., 2012). Green innovation is divided into four categories; managerial, product, process, and technological innovation (Tseng et al., 2013). Technological innovation preserves environmental interests through the deployment of green technology that accelerates the process of green growth, which ultimately reduces the potential threats of climate change to human lives (Li & Long, 2020). Johnstone et al. (2010) suggested that technological innovation is imperative for green growth development. Danish & Ulucak (2020) examined how technological change affects green growth in BRICS countries. Using CO_2 as a proxy for green growth, the authors argued that technology is critical in green growth transition. Ahmad et al. (2020) considered technological innovation to be an essential determinant of green growth. They stated that technological innovations transform traditional technology into a cleaner one to protect the environment and improve operational efficiency. This study is endorsed by previous research by Aghion et al. (2016) who argued that technological innovation should be blended into policy plans to promote green growth. Figure 1 presents the relationship between technological innovation and green growth.

Studies have estimated technological innovation using R&D funding and patent applications (Zhai & An, 2021). Aghion et al. (2005) used patents application as indicators of technological innovation. Berghäll (2016) measured R&D as a representative of innovation. The results of the study by Audretsch and Belitski (2020) and Shaikh and Colarelli O’Connor (2020) showed that

R&D is vital to innovation in an organization and improves productivity. The authors further stated that the impact of R&D may differ across countries and depends on the variables under study. According to Wang and Zhu (2020), technological innovation is essential to reduce carbon dioxide emissions. R&D funding and investments promote technologies, reducing CO_2 and other GHG emissions (Jung et al., 2012; Sohn and Han, 2015). According to Fernández et al. (2018), R&D funding is effective in minimizing CO_2 emissions. Song et al. (2019) stated that not only does technological innovation meet national energy demands by promoting cleaner technologies, but it also reduces CO_2, GHG emissions, and other harmful pollutants that impose threats on human lives (Bekun et al., 2019).

In contrast to the above literature, several studies (Fisher-Vanden & Sue Wing, 2008; Wang et al., 2014; Zhao et al., 2010) have claimed that technological innovation enhances production capacity that requires more energy consumption, resulting in harmful emissions. Furthermore, Chen & Lee (2020) and Samargandi (2017) disclose that technological innovation does not impact global CO_2 emissions and does not significantly protect the environment. Therefore, this inconsistency within the literature motivates us to extend our analysis. For decades, technological innovation has been considered as a core aspect of national growth. However, the literature regarding technological innovation and green growth is limited (Popp, 2012). Therefore, based on the aforementioned contradictory literature and with purpose of exploring the impact of technological innovation on green growth in the context of a developing country, we propose the following hypotheses:

Hp1: Patent application is positively related to green growth

Hp2: R&D is positively related to green growth

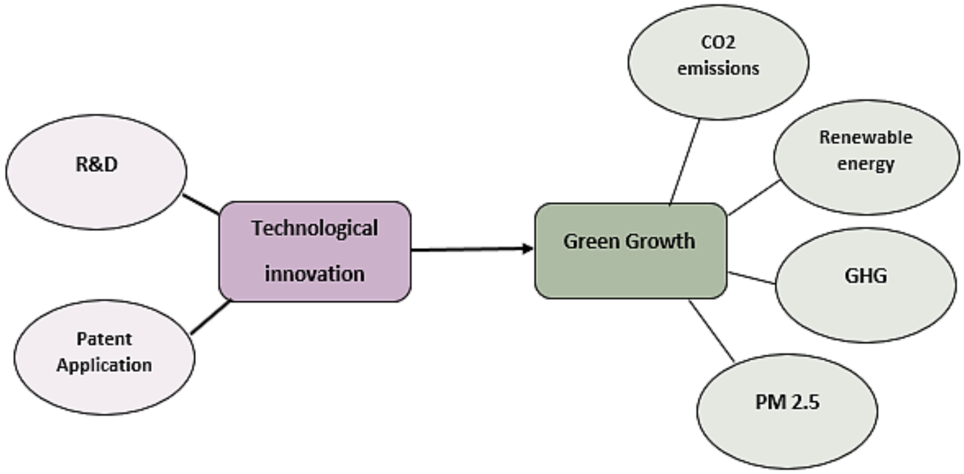

Figure 1. Technological innovation and green growth

2.2 Green organizational innovation, ISO 4001, and green growth

Daunting environmental challenges call for organizational support to preserve and protect the environment. Environmental Management Systems (EMSs) are the environmental sustainability tools that help organizations address environmental challenges and ensure environmental sustainability. A number of EMSs exist, but ISO 14001 is the most adapted management standard worldwide. ISO 14001 was established in 1996 by the international Organization for Standardization (ISO) and it has been revised over the years. ISO 14001:2015 is the latest version with a set of updated requirements to improve environmental performance (da Fonseca, 2015). After ISO 14001, the second most famous EMS standard is the Eco-Management and Audit Scheme (EMAS) designed and established by the European Regulation EC 1221. EMSs make organizations follow specific rules to handle environmental management aspects both internally and externally (Chiarini, 2017; Testa et al., 2014).

According to Konnola and Unruh (2007), EMS is a substantial part of managerial innovation, ensuring efficiency in process control, production improvement, and product quality. Hence, EMS can be seen as a management standard applied to the whole industrial network. Curkovic and Sroufe (2011), Ikram et al. (2020) argued that EMS is not just a part of environmental improvement;

an organization can also use EMS to create a positive public image and involve managers from different hierarchical levels to engage in innovation. Similarly, said EMS is a key instrument introduced to promote product innovation. The research conducted by Kammerer (2009) reveals that green practices (drawn from EMS) and innovations in an organization share a positive relationship. EMS ensures environmental efficiency and enhances organizational innovation capabilities (Darnall, 2006).

This study mentions and employs ISO 14001 because EMAS has not yet been implemented or established in Pakistan. ISO 14001 serves as a part of the Environmental Management System and involves the planning, coordination, processing, resource deployment, implementation and evaluation of an environmental policy (Darnall et al., 2008). In the last two decades, a global trend to adopt EMS has been observed. EMS has proven to be efficient in addressing environmental issues and increasing organizations' accountability in considering environmental concerns (Mazzi et al., 2017). ISO 14001 certifications help organizations achieve environmental goals and provide a way to design and manage organizational operations with superior environmental performance (Carrillo-Labella et al., 2020).

Aravind (2012) argued that in order to implement proper practices to improve environmental performance in an organization, the management enhances process innovation and environmental audit. To obtain ISO 14001 certifications, organizations need to comply with ISO standards and requirements. First, organizations must develop an environmental report mentioning all the potential activities, impacts, goals, and plans to minimize environmental impact. Second, organizations must disseminate information about ISO 14001 with employees at different levels, train them, and systematically handle environmental issues. Henriques and Sadorsky (2007) and Naveh et al. (2006) define ISO 14001 as an administrative innovation within an organization that promotes process-oriented practices. These innovations facilitate organizational change in management practices and operations (Walker et al., 2011). According to Wagner (2010), understanding the ISO 14001 as a measure of organizational innovation is not simple. Aragón et al. (2007); Ziegler et al. (2009) argued that ISO 14001 increases environmental performance by reducing harmful impacts and improves organizational performance by channeling innovation capabilities. EMS drives innovation capabilities in management practices and environmental processes (Bansal & Hunter, 2003). The advantages of ISO 14001 compel multiple economies to support EMS deployment by providing financial and technical support to organizations (Konnola & Unruh, 2007).

EMS helps organizations consistently and systematically tackle significant environmental issues, including air pollution. Countries must facilitate EMS adoption if they want to reduce air pollution (Raines, 2002). The updated ISO 14001:2015 incorporated various aspects of energy consumption and emphasized the use of process, operational techniques, and resources that do not discharge harmful air pollutants, emissions, or other residual waste to avoid environmental impacts. ISO:14001:2015 thereby supports the goal of green growth by stressing the need for clean energy sources/materials and techniques (technologies) to minimize drastic emissions and avoid harmful impacts on the environment (Laskurain et al., 2017).

The literature shows the importance of EMS in environmental protection and sustainable development, but despite adopting ISO-14001, contradictory results worldwide make it controversial. There is no globally unified EMS result (Boiral and Henri, 2012; Clare et al., 2019), which has forced this study to incorporate EMS into its framework and verify its role in green growth development in Pakistan with other variables. There is a direct relationship between EMS and green growth, and it is presented in Figure 2.

Therefore, we propose the following hypothesis:

Hp3: Green forms of organizational innovation (i.e., EMS) are positively related to green growth

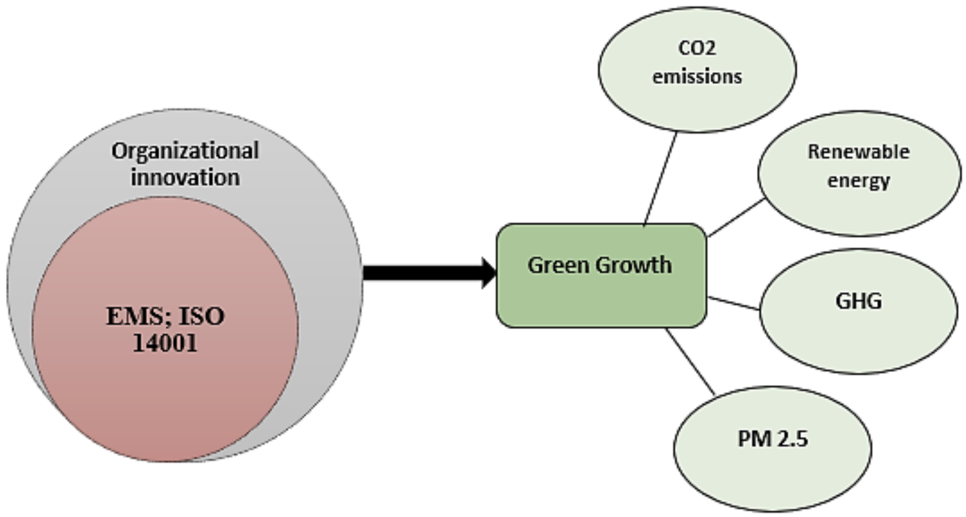

Figure 2. EMS and green growth

2.3 Environmental challenges and green growth

Energy consumption has contributed to the growth of economies around the world, but it has also damaged the environment over the years. Energy consumption has played a substantial role in the global environmental crisis (Sato, 2007). Alkaher & Carmi (2019) stated that the environmental catastrophe is a byproduct of human activities worldwide. They further argued that population growth is among the most significant causes of the environmental crisis, which should be addressed next.

This study incorporates the two most significant environmental challenges into its framework; the first environmental challenge is represented by energy consumption, and the second is population growth, presented in Figure 3. Since the industrial revolution, fossil fuels have been the dominant driver of world economies used to enhance production and meet the increasing population demands. Increased energy consumption leads to soaring emissions of CO_2 and other GHGs (Hamit-Haggar, 2012). GHGs are considered to be the main factor responsible for global climate change and a significant threat to the environment and humanity (Davis et al., 2018; Miao, 2017).

The primary source of pollution is energy consumption from traditional energy sources like coal, gas, and oil in various industries, including energy and transportation (Odeh & Cockerill, 2008). Human activities have increased the level of air pollution (Feng et al., 2019). Air pollution is a threat to human lives and other species sharing the same environment (Ruggieri & Plaia, 2012). Besides CO_2 and GHG emissions, PM 2.5 is the most dangerous particulate matter in the air. The most harmful impact on human lives is a byproduct of fossil fuels released from power plants in factories and vehicles**.** PM 2.5 is a heavy air pollutant responsible for severe lung and heart conditions (Wu, 2017). Previous studies have shown that GHGs and PM 2.5 are the result of the overuse of fossil fuels and mass industrial production (Kantor et al., 2010).

Zhang et al. (2021) suggested replacing fossil fuels with renewable energy sources to minimize harmful gas emissions. One of the best strategies to reduce CO_2 emissions is to prefer renewable energy consumption. Their use will protect the environment and human species from harmful emissions and serve as a tool to achieve sustainable development (Sandberg et al., 2019). In their studies, Danish and Ulucak (2020); Odeh and Cockerill (2008) emphasized the use of renewable energy consumption and argued that the establishment should help the public and private sectors reduce their reliance on conventional energy. Most of Pakistan’s energy consumption comes from fossil fuels. The combustion of fossil fuels has caused a surge in CO_2 emissions in Pakistan, thus resulting in a prolonged environmental crisis (Latif et al., 2014).

Population growth represents the second dimension of environmental challenges that we included in our research. Since the industrial revolution, population growth and excessive energy consumption produced from fossil fuels have disturbed the environment and posed a threat to younger generations (Smith et al., 2013). Air quality represents environmental quality, thus environmental crisis and air quality are interlinked (Roberts & Wooster, 2021; Shi & Wu, 2020). Javed et al. (2019) disclosed that in developing economies, the leading cause of CO_2 emission is population and traditional energy sources of production. The research findings of Sulaiman and Abdul-Rahim (2018) showed that population growth is one of the most significant drivers of CO_2 emissions.

Rehman et al.(2020) reported that energy consumption is the primary cause of emissions, but population growth is also causing CO_2 emissions as humans are natural emitters of carbon dioxide. Cui et al. (2018) analyzed various social and economic indicators and found that population growth increases CO_2 emissions. Naqvi and Rehm (2014) and Abid et al. (2020) examined Pakistan's socioeconomic and environmental variables and revealed a positive relationship between population growth and CO_2 emissions. With every 1% increase in population, there will be a 0.46% increase in CO_2 emission, a significant reason behind its deforestation, and fewer initiatives to protect and sustain Pakistan's natural environment. Uncontrolled population growth demands more energy and sources and exerts pressure on the environment, and in the absence of proper precautionary measures, the ecological system will suffer.

Therefore, we propose the following hypotheses:

Hp4: Energy consumption is negatively related to green growth.

Hp5: Population growth is negatively related to green growth

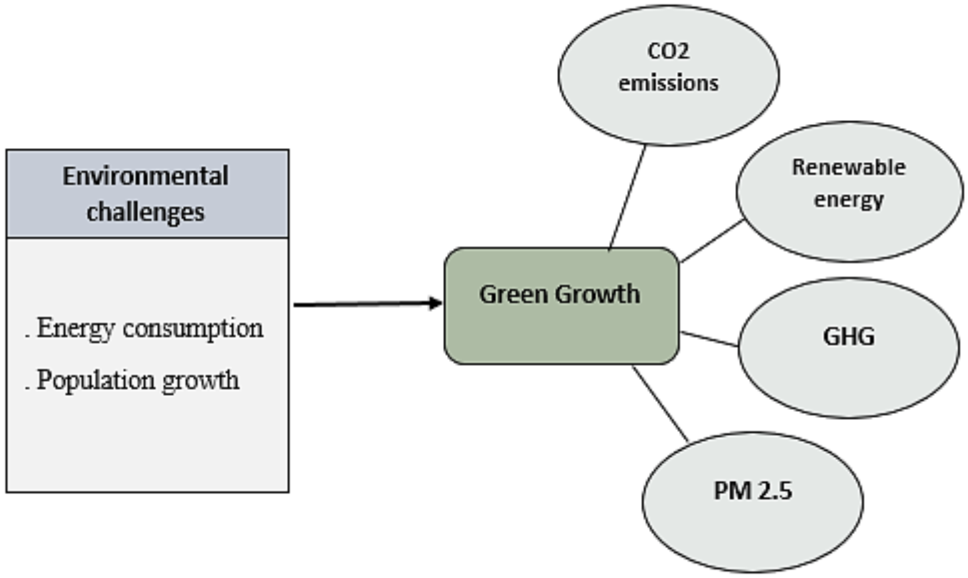

Figure 3. Environmental challenges and Green Growth

This study develops a multi framework by incorporating technological innovation, green organizational innovation, and environmental challenges with green growth. It expands the range of desirable outcomes responding to Pakistan's green growth development and environmental goals. We aim to test the impact of independent variables on green growth by employing the GRA approach. The analytical model summarizing all the hypotheses and variables used in the study is reported in Figure 5.

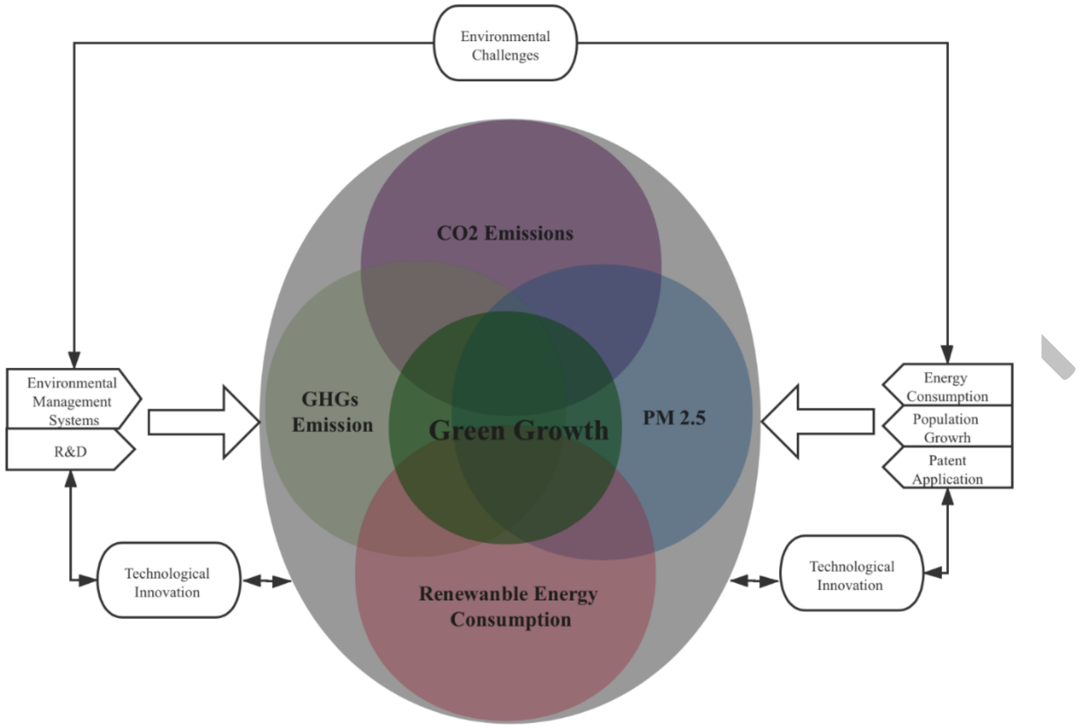

Figure 4. Conceptual model

3. Research Methodology

This study aimed to explore the potential impact of technological innovation, EMS, environmental challenges (i.e., energy consumption and population growth) on green growth in Pakistan. In order to gain a better understanding of technological innovation, the study used research and development (R&D) and patent applications (PA) as a proxy of technological innovation (Aghion et al., 2005; Berghäll, 2016). EMS such as ISO 14001 certifications were considered since Pakistan has not implemented EMAS yet. ISO 14001 represents the number of organizations in Pakistan that have implemented EMS. Energy is measured in terms of energy consumption, and population as the percentage of population in Pakistan. Green growth is measured in terms of air pollution, with PM 2.5 (particulate matter) considered as the most dangerous air pollutant and a significant threat to human lives (Diao et al., 2019), GHGs, renewable energy consumption (REC), which is the crucial strength factor to produce clean energy and promotes sustainable development (Abid et al., 2021). Data from 2000-2019 were used, and a complete description of variables and data collection sources is reported in Table 1.

Table. 1 Description of study variables

Variables (Code)	Description of variables	Measurement	Data sources
R&D	R&D expenditure	Research and development expenditure, percent of GDP	Database of Business and economic data
PA	Patent applications	Number of patents applications	WGI
EC	Energy consumption	Energy consumption in the industrial sector	Our world in Data
EMS	EMS	ISO 14001 certifications	ISO
PG	Population growth	Population growth	WGI and Database of Business and economic data
REC	Renewable energy consumption	Percentage of renewable consumption (TWh)	Our world in data
GHG	Greenhouse gas emissions	GHG in the agricultural sector (%)	WGI
CO2	Carbon dioxide emissions	Annual CO_2 emissions (mt)	Our world in data
PM 2.5	Air pollution/Particulate Matter 2.5	Mortality from exposure to ambient PM2.5 (Per 1 000 000 inhabitants)	OECD

3.1 Grey Relational Analysis (GRA))

The Grey relational model, known as the GRA model, has received enormous recognition in the past two decades. GRA models are applied in different fields of study, including management, engineering, economics, environmental science, and medicine (Xu & Li, 2018). GRA methods of data analysis have emerged as an attractive option as they provide an advantage over other techniques in several ways. GRA allows for efficient handling of small datasets, dealing with grey values, and providing optimal results (Ikram et al., 2021).

In the present study, GRA models consist of four stages. For the analysis, data were extracted from multiple databases from 2000 to 2019 and normalized in the first stage. In the second stage, GRA models were run on the data to examine the relationship that technological innovation (PA and R&D), energy, environmental management systems (EMS) (ISO 14001), and population growth (PG%) have with green growth (GHG emissions, PM 2.5, CO_2 emissions and renewable energy) in Pakistan. The third stage involved the use of the GRA ranking approach, employing the weights generated in stage two, and after defining the decision criteria, assigning them to the alternatives. In the last stage, the conservative model was run on the analysis results to find the best solution (the variable or set of variables), having a substantial impact on green growth development in Pakistan.

In 1982, Deng developed the grey system theory (Ju-Long, 1982). GRA models, also known as Grey Incidence Analysis (GIA), are considered to be the key elements of Deng's grey system theory (Badri Ahmadi et al., 2017). These models are superior to other approaches in tackling data issues, whether they contain missing values or unreliable data sources (Ikram et., 2019). They also assist in handling small datasets with maximum efficiency (Rehman et al., 2020). According to Dai et al. (2014), GIA models provide better grounds for understanding the complexity of the conceptual model. Similarly, s objectives. Recently, in his work, Mahmoudi et al. (2018) explained the systematic process and steps to measure Deng's GIA model of two datasets represented as ω_0 and ω_η.

- Stage 1: as a first step to measure Deng's GIA, we present the equation of our two datasets δ_0 and δ_i, i=1, 2, 3…, m, where:

$$\omega'\eta = \frac{\omega\eta}{\omega\eta(1)} = \left(\omega'\eta(1), \omega'\eta(2), \dots, \omega'\eta(\mathrm{n})\right); \eta = 0,1,2,3,4 \dots, \mathrm{m}. \quad (1)$$

- Stage 2: involves the calculation of the differences in the δ_0' and δ_i' sequence, where η =1, 2,3,4 …, m and is presented as

$$\Delta\eta(\mathrm{I}) = || \ \omega'0(\mathrm{I}) - \omega'\eta(\mathrm{I}) \ ||, \Delta = \big(\Delta\omega(1), \Delta\omega(2), \dots, \Delta\omega(\mathfrak{n})\big), \eta = 1,2,3, \dots, \mathfrak{m}. \quad (2)$$

- Stage 3: we attempt to find the difference (maximum and minimum) between:

$$\mathbb{M} = max_{\eta} max_{\mathrm{I}} \Delta_{\eta}(\mathfrak{T}), \quad (3)$$

$$\mathfrak{m} = max_{\eta} max_{\mathrm{I}} \Delta_{\eta}(\mathfrak{T}), \quad (4)$$

- Stage 4: we attempt to measure the grey incidence coefficient with the help of the following formula, where ς is the distinctive coefficient and has the value of 0.5:
- Stage 5: Grey relational degree (GRG) is measured with equation (5)

$$\xi 0\eta = \sum \mathfrak{T} = 1\mathfrak{n}(\xi 0\eta(\mathfrak{T}) \times w\mathrm{I}); \eta = 1,2,3,4 \dots, \mathfrak{m}. \quad (5)$$

In equation (5) $\sum w$I=1 and $\frac{1}{\mathfrak{n}}$ represents equally distributed criteria (Sarikaya & Güllü, 2015).

3.1.1 Absolute degree of GIA model

Deng's GIA model works better than traditional statistical methods to explain the relationship between study variables (Ikram et al., 2021). It is known as the Absolute GRA model or Absolute degree of GIA (ADGIA) (J. Xu & Li, 2018; Zhicai & Li, 2018). Using this rigorous econometric technique in the investigation allows the researchers to gain insights into the geometric proximity between the sequential study setup and the information on study parameters and their association with the designed framework (Ikram et al., 2021; Javed & Liu, 2017). In order to analyze the GIA in the study model, it is necessary to access the two separate time periods ω_0 and ω_η.

- Stage 1: Using the different time intervals ω_0 and ω_η to measure the base point ω_0^0 and ω_1^0.

- Stage 2: Estimate $|\gamma_0|, |\gamma_1|$ and $|\gamma_1 - \gamma_0|$.
- Stage 3: calculate the μ_{01}) ADGIA different time span using the δ_0, δ_1 sequence. The formula used to estimate the ADGIA is given below:

$$\mu_{01} = \frac{1+|\gamma_0|+|\gamma_1|}{1+ |\gamma_0|+|\gamma_1|+|\gamma_1-\gamma_0|}. \tag{6}$$

3.1.2 Deng's degree of GIA

In the following stage of the analysis, the GRA model proposed by Deng suggests employing Deng's degree known as GRG (Grey Relational Grade) or DGIA (Degree of Grey Incidence Analysis). The mathematical representation of DGIA is given below in equations (7) and (8), where $\xi_{0\eta}$ $(\mathfrak{T})$ is a grey relational coefficient (GRC).

$$\xi_{0\eta} = \sum_{\mathfrak{l}=1}^{\mathfrak{n}} \left(\xi_{0\eta}(\mathfrak{T}) \times \lambda_{\mathfrak{l}}\right);\ \eta = 1,2,3,4\ \ldots,\ \mathfrak{m}, \tag{7}$$

Or

$$\xi_{0\eta} = \frac{1}{\mathfrak{n}} \sum_{\mathfrak{l}=1}^{\mathfrak{n}} \left(\xi_{0\eta}(\mathfrak{T})\right);\ \eta = 1,2,3,4\ \ldots,\ \mathfrak{m}, \tag{8}$$

Equation (7) represents the weighted GRA/DGIA, and equation (8) shows the non-weighted scheme.

Definition I: Absolute Degree of Grey Incidence Analysis (ADGIA)

This study used the ADGIA model to estimate the weights of technological innovation, energy, environmental management systems, population growth, and green growth for Pakistan's case.

The formula for weight measurements is given below:

$$\beta 01 = \frac{1 + |\gamma 0| + |\gamma 1|}{1 + |\gamma 0| + |\gamma 1| + |\gamma 1 - \gamma 0|} \tag{9}$$

Let the data sequence of system behavior be represented as$\omega_\eta = (\omega_\eta(1), \omega_\eta(2), \ldots.., \omega_\eta(\mathfrak{n}))$ and $\mathcal{C}$ indicate the sequence operator , which satisfies $\mathrm{d}\,\delta_\eta(L)c = (\omega_\eta(L)c - \omega_\eta(1);\ \mathfrak{T} =$ $1,2,3,..\mathfrak{n}$ Then, $\mathcal{C}$ is a point operator starting from zero and $\delta_i C$, known as zero-scale point image of δ_i. $\delta_i C$, is often written as:

$$\omega_\eta \mathcal{C} = \omega_1^0 = (\omega_\eta^0(1), \omega_\theta^0(2), \ldots.. \omega_\eta^0(\mathfrak{n})) \tag{10}$$

According to Liu et al. (Liu et al., 2017), we assume that the length of variables δ_i and δ_j are the same as the one-time-interval sequences, and δ_i and δ_j are zero-starting point images as follows:

$$\omega_\eta^0 = \left(\omega_\eta^0(1),\ \omega_\eta^0(2), \omega_\eta^0(3)\ \ldots,\ \omega_\eta^0(\mathfrak{n})\right), \tag{11}$$

$$\omega_\theta^0 = \left(x_\theta^0(1),\ \omega_\theta^0(2), \omega_\theta^0(3)\ \ldots,\ \omega_\theta^0(\mathfrak{n})\right). \tag{12}$$

Then

$$|\varsigma_\eta| = \left[\sum_{\mathrm{I}=2}^{\mathfrak{n}-1} \omega_\eta^0(\mathfrak{T}) + \frac{1}{2}\omega_\eta^0(\mathfrak{n})\right] \tag{13}$$

$$|\varsigma_\theta| = \left[\sum_{\mathrm{I}=2}^{\mathfrak{n}-1} \omega_\theta^0(\mathfrak{T}) + \frac{1}{2}\omega_\eta^0(\mathfrak{n})\right], \tag{14}$$

$$|\varsigma_\eta - \varsigma_\theta| = \left[\sum_{\mathrm{I}=2}^{n-1} (\omega_\theta^0(\mathfrak{T}) - \omega_\eta^0(\mathfrak{T})) + \frac{1}{2}\left(\omega_\eta^0(\mathfrak{n}) - \omega_\theta^0(\mathfrak{n})\right)\right], |\varsigma_\theta|$$

$$= \left[\sum_{\mathrm{I}=2}^{\mathfrak{n}-1} \omega_\theta^0(\mathfrak{T}) + \frac{1}{2}\delta_\eta^0(\mathfrak{n})\right], \tag{15}$$

3.2 SSDGIA model (Second Synthetic Degree of Grey Incidence Analysis)

The SSGIA model is the next stage to calculate the proximity between two curves using the two data sequences mentioned earlier. This model presents the whole proximity of the factor series. SSDGIA is measured by incorporating the integral and partial points of the proximity between the curves. This model is proposed by Javed and Liu (2018) and estimated with the help of the following equation:

$$\beta_{\eta\theta} = \delta\epsilon_{\eta\theta} + (1-\delta)\varpi_{\eta\theta};\ \delta\varepsilon\ [0,1], \qquad (16)$$

$\beta_{\eta\theta}$ = SS degree of grey relation (SSGRG)

$\epsilon_{\eta\theta}$ = Absolute Degree of grey relation (absolute GRG)

$\varpi_{\eta\theta}$ = Deng's degree of grey incidence/grey relation (GRG)

The basic principle behind GRA models is to utilize the degree of proximity for a geometric curve in an open data structure to evaluate for associations (Liu et al., 2017, p.68). There are three types of proximities in GRA models. If Deng's GRA model relates partial closeness/proximity, then absolute GRA relates integral closeness/proximity between two data sequences, while the second synthetic GRA aims to reveal a more comprehensive closeness/inclusive proximity (Ikram et al., 2021; Javed et al., 2019). The SSDGIA model was developed based on the SDGIA model's working standard. It is recommended that θ=0.5 be considered when making decisions with a view to achieving a thorough positioning that equally combines the advantages of the two terms, i.e., γ and ε, without preferring one over the other, and if appropriate, θ could be changed. If someone wants to endorse γ, then the calculation of θ might be decreased at that point, but ε is desired then the total value can also be increased at that point.

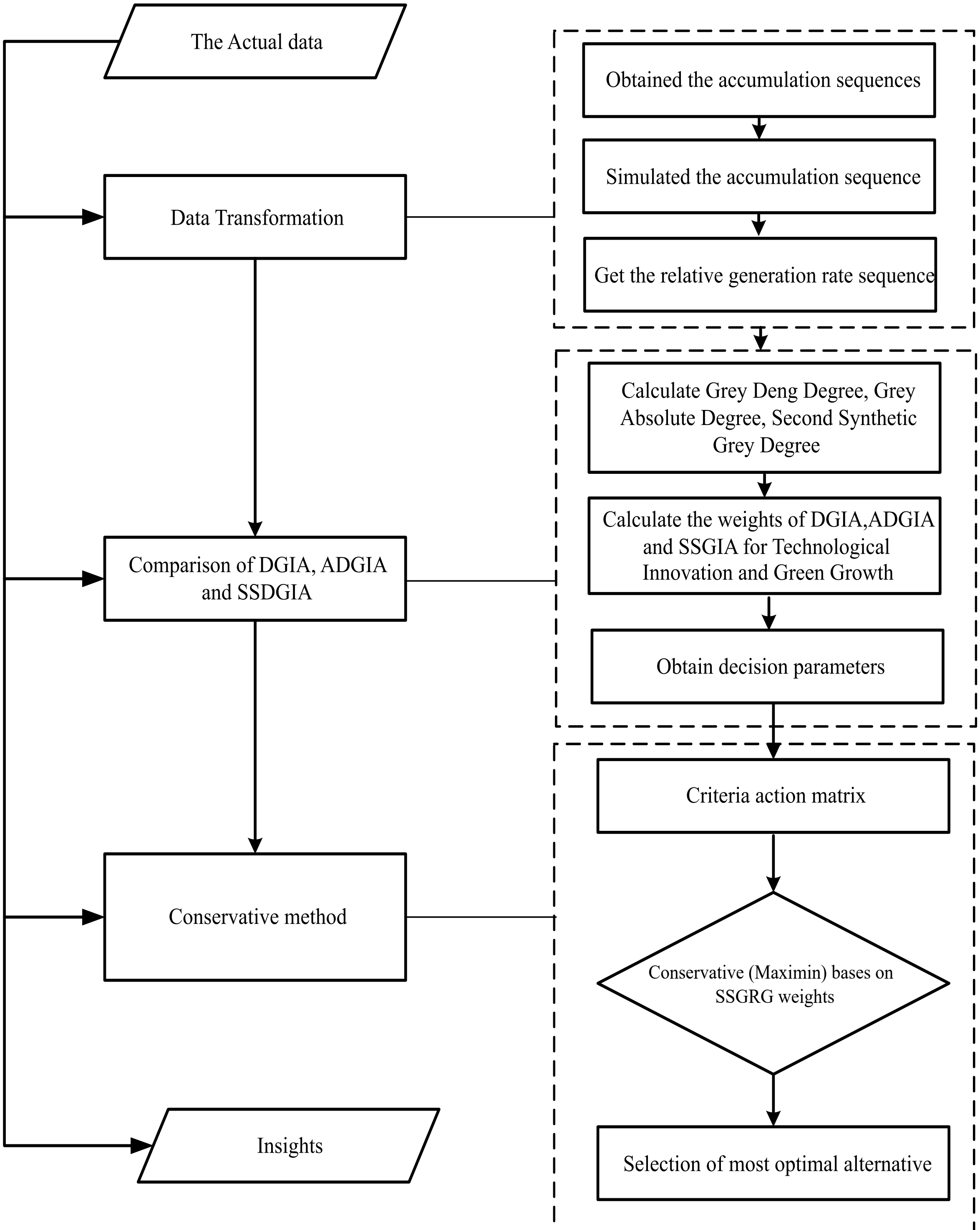

***Figure 5**:* Schematic framework of the study; *Source (Ikram et al., 2021)*

4. Results and Discussion

This study used GRA models to analyze the relationship between technological innovation, EMS, energy consumption, population growth, and green growth in Pakistan. The efficiency of GRA models makes them a better technique as they address endogeneity issues and grey values, thus providing an optimal solution (Badri Ahmadi et al., 2017). The analysis results for GRA models, Deng GRG, SSGRG, and absolute GRG, are set forth in Tables 2 to 6. GRA models help us evaluate the association between technological innovation (R&D, Patent Application), EMS (ISO 14001), energy consumption, population growth, and green growth (CO_2 emissions, renewable energy, GHGs, PM 2.5) in Pakistan for the period of 2000-2019. The strength of this relationship is measured using a scale of 0 to 1, where 0 represents the weakest values, and 1 indicates the most substantial relationship for GRG and SSGRG models. The Deng GRG model's scale has a standardized value of 0.5 to 1, where 0.5 indicates a weak relationship, and 1 shows a strong relationship between study variables (Ikram et al., 2020; Javed et al., 2019). The assessment of technological innovation (R&D, Patent Application), EMS (ISO 14001), energy consumption, population growth, and green growth (CO_2 emissions, renewable energy, GHGs, PM 2.5) with respect to GRA models is presented in Figure 6.

Table 2: Grey Relational assessment for Research and Development

Country	Absolute GRG	Deng GRG	SSGRG
GHG Emission from Energy	0.5308	0.6791	0.6049
Renewable energy consumption	0.8394	0.6882	0.7092
Mortality from exposure to pm 2.5	0.9112	0.7963	0.8537
CO_2 emissions	0.9791	0.7330	0.8561

Table 2 shows the relationship between technological innovation (R&D) and green growth (CO_2 emissions, renewable energy, GHGs, PM 2.5) in Pakistan. Absolute GRG results show that CO_2 emissions have a substantial relationship with green growth in Pakistan with a value of 0.9791followed by PM 2.5 (0.9112), which represents the most dangerous air pollutant for human health. Deng GRG results show that PM 2.5 got the highest-ranking value (0.7963), followed by CO_2 emissions (0.7330). PM 2.5 is responsible for severe lung and respiratory diseases and deaths (Diao et al., 2019). According to WHO, every year, 40 million cases and 28,000 deaths due to severe lung and respiratory diseases are reported in Pakistan (Environmental health, 2020). Results of R&D as an independent variable in Table 1 indicate the significant relationship between CO_2 and PM 2.5 emissions, which means that government spending on R&D will help Pakistan address CO_2 and PM 2.5 problems nationwide.

The SSGRG model findings rate CO_2 emission in first position (0.8561) with R&D and PM 2.5 (0.8537) in second position. The third position is occupied by renewable energy consumption with a value of 0.7092. Pakistan relies on fossil fuels to meet most of its energy and other economic demands. Although the country has launched various initiatives to support renewable energy production, most of Pakistan's future energy projects are still based on fossil fuels (Abid et al., 2020).

GRA assessment for R&D shows that GHG emissions from energy consumption in Pakistan do not share any significant relationship with R&D funding. Our results for PM 2.5 and CO_2 emissions are in line with the findings of (Di Vita, 2017) and (Zhang et al., 2019), whose research revealed that technological innovation (R&D funding) helps lower CO_2 emissions and air pollution (PM 2.5) in a country. R&D funding in Pakistan is insufficient (Global economy, 2021) to boost its technological innovation, so the government should focus on these aspects to protect people's lives or aim to comply with international environmental laws.

Table 3: Grey Relational assessment for patent applications

Country	Absolute GRG	Deng GRG	SSGRG
GHG Emission from Energy	0.5238	0.6814	0.6026
Renewable energy consumption	0.6851	0.6992	0.6921
Mortality from exposure to pm 2.5	0.8179	0.7312	0.77462
CO_2 emissions	0.8705	0.7322	0.8013

Patent applications are a good proxy for measuring technological innovation in a country (Aghion et al., 2005; Berghäll, 2016). Table 3 shows the relationship between patent applications (independent variable) and CO_2 emissions, renewable energy, GHG emissions, PM 2.5 (dependent variable). The result of absolute GRG shows that CO_2 emissions with a weight value of 0.8705 share a significant relationship with patent applications in Pakistan, followed by PM (0.8179). Deng GRG and SSGRG models show similar results as absolute GRG, and rank CO_2 emissions (0.7322 and 0.8013), PM 2.5 (0.7312, and 0.7746) as factors that directly influence patent applications in the country. These findings are similar to the results of (Geng, 2016). These researchers found that patent applications are crucial factors that help lower CO_2 and other harmful emissions. There is a negative relationship between Technological innovation and CO_2 emission, which postulates that technological innovation can lead to a decrease in CO_2 emissions for Pakistan (Abid et al., 2020). However, as for Pakistan, renewable energy and GHG emissions share a significant relationship with patent applications. The number of patent applications is not progressing compared to other developing countries in Asia (The world bank, 2018). There is a need to nourish technological innovation in Pakistan to achieve environmental sustainability.

Table 4. Grey Relational assessment for Energy consumption

Indicators	Absolute GRG	Deng GRG	SSGRG
GHG Emission from Energy	0.5436	0.4455	0.4945
Renewable energy consumption	0.5391	0.5455	0.5923
Mortality from exposure to pm 2.5	0.9292	0.6823	0.7658
CO_2 emissions	0.8683	0.6959	0.7821

GRA results for energy consumption with GHG emissions, renewable energy, CO_2 emissions, and PM 2.5 are presented in Table 4. Surprisingly, absolute GRG ranks PM 2.5 as the indicator that is most affected (0.9292) by energy consumption in Pakistan. According to a World Bank report, 30 million people in Pakistan suffer from severe respiratory conditions every year, leading to 28000 deaths (World Health Organization, 2020). PM 2.5 is the most harmful air pollutant responsible for lung and chronic reparatory diseases (Diao et al., 2019). Pakistan produces most of its energy from fossil fuels (Wakeel et al., 2016), and our findings indicate that energy consumption is a significant cause of the rising level of PM 2.5. CO_2 emissions (0.8683) rank second among the various factors that are most affected by energy consumption. However, the results of Absolute GRG, Deng GRG, and SSGRG suggest that factories' energy consumption does not share a significant relationship with GHG emissions since more than 70% of GHG emissions is caused by agriculture in Pakistan (Hussain et al., 2019). Deng GRG and SSGRG support the results of Absolute GRG that PM 2.5 (0.6823 and 0.7658) and CO_2 emissions (0.7821 and 0.6959) are the main outcomes of energy consumption in Pakistan.

Table 5: Grey Relational assessment for EMS

Indicators	Absolute GRG	Deng GRG	SSGRG

GHG Emission from Energy	0.6143	0.9424	0.7797
Renewable energy consumption	0.5952	0.8975	0.7523
Mortality from exposure to pm 2.5	0.6307	0.6392	0.6850
CO_2 emissions	0.6267	0.9788	0.7824

When we use EMS as an independent variable, the results of Deng GRG models show that EMS is strongly associated with CO_2 emissions with a weight of 0.9788. The second variable is GHG emissions (0.9424), which indicates the effectiveness of EMS in addressing environmental issues in Pakistan. Renewable energy also shares a significant relationship with EMS (0.8975), and PM 2.5 has a comparably weak relationship with EMS (0.6392) in Pakistan. The details are given in Table 5. The results of SSRG place CO_2 emissions first, followed by GHG emissions and renewable energy consumption. Our findings for EMS affecting renewable energy are similar to the results of (Bellakhal et al., 2019; Horbach and Rennings, 2008). The absolute GRG shows that EMS effectively lowers air pollutants, and the PM 2.5 value is 0.6307. However, Deng GRG and SSGRG models show that EMS (ISO 14001) shares a more significant relationship with CO_2 and GHG emissions. These outcomes align with the findings of (Muhammad et al., 2020), who also show in their analysis that ISO 14001 lowers CO_2 and GHG emissions. Organizations in Pakistan tend to employ EMS (ISO 14001) to improve environmental performance, but the number of organizations adopting ISO certifications is not promising (Muhammad Ikram et al., 2020).

Table 6: Grey Relational assessment for Population

Indicators	Absolute GRG	Deng GRG	SSGRG
GHG Emission from Energy	0.5201	0.5003	0.5602
Renewable energy consumption	0.6868	0.8204	0.7036

Mortality from exposure to pm 2.5	0.5158	0.5866	0.6012
CO_2 emissions	0.6981	0.7601	0.7241

Table 6 presents the relationship between population growth and GHG emissions, renewable energy, PM 2.5, and CO_2 emissions in Pakistan. Absolute GRG, Deng GRG, and SSGRG indicate that Pakistan's population growth is somehow responsible for CO_2 emissions as humans are natural emitters of CO_2 (Naqvi and Rehm, 2014). The positive association between CO_2 emissions and population growth is backed by the results of (Naqvi and Rehm, 2014), who found a positive correlation between population and CO_2 emissions (Abid et al., 2020).

Population growth does not share a substantial relationship with GHGs and PM 2.5 in Pakistan. The second significant factor that is related to population growth is renewable energy consumption in Pakistan for all three GRA models. The reason behind this factor is the awareness regarding environmental protection among the people. The study of Vo & Anh (2021) also verified this result and asserted that the population needs energy; as the population grow, so does its energy consumption. With rising awareness of the consequences of fossil fuel energy consumption, people tend to demand energy produced through clean energy sources. The relationship between renewable energy and population is also explained by Avtar et al. (2019), who stated that the population exerts pressure on domestic authorities to use alternative energy sources in the country. Therefore, a change in population is also subject to a change in the proportion of energy consumption from renewable energy sources.

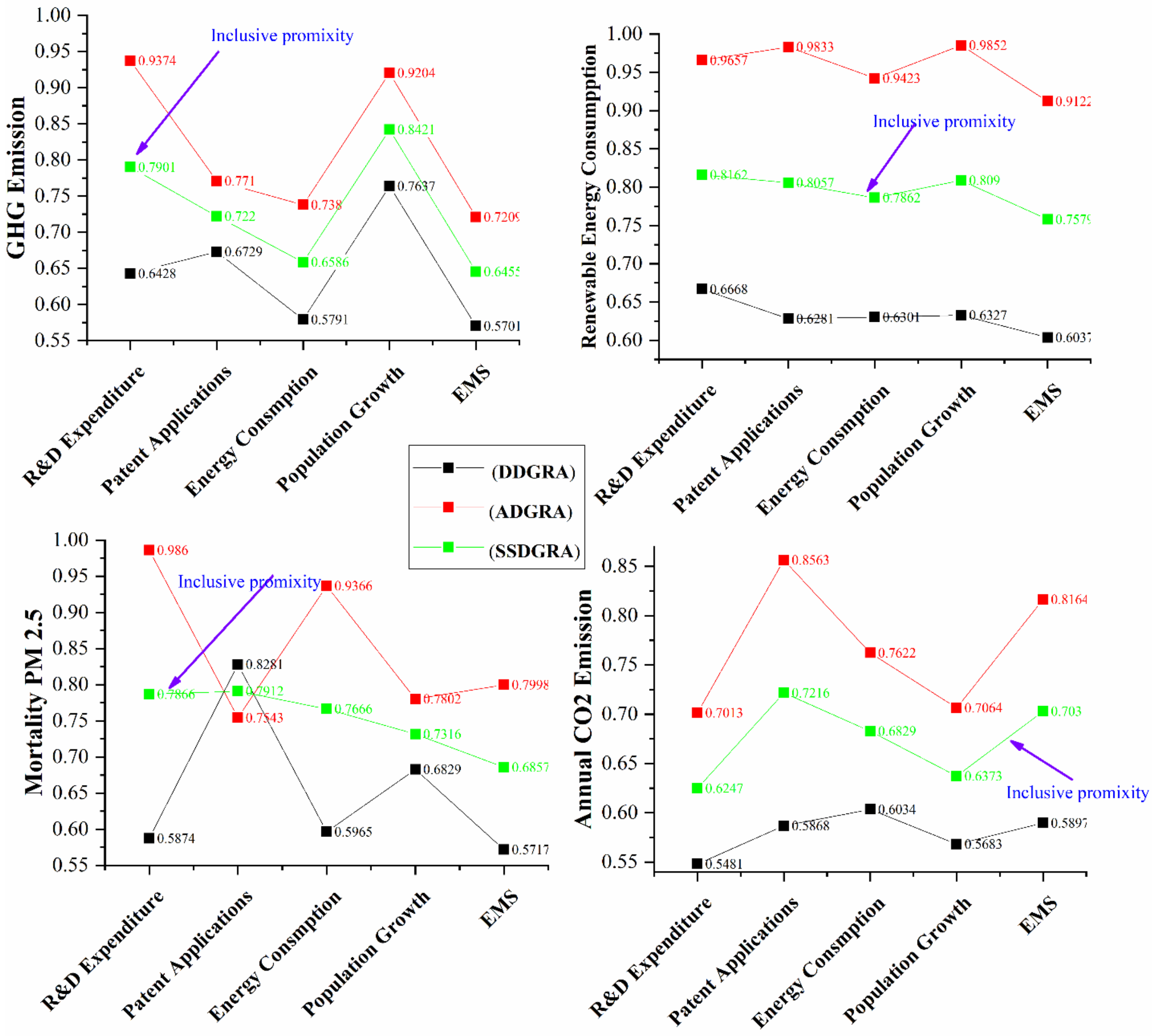

Figure 6: GRA based evaluation of technological Innovation and Green Growth

Table 7: Grey Assessment Ranking of technological innovation, EMS, energy, population, and green growth

Indicators	Grey Relational Model	Ranking
Research and Development expenditure	Absolute GRG	CO_2 emissions > Mortality from exposure to pm 2.5> Renewable energy consumption > GHG Emission
	Deng's GRG	Mortality from exposure to pm 2.5> CO_2 emission > Renewable energy consumption > GHG Emission
	SS GRG	CO_2 emissions > Voice and Accountability> Mortality from exposure to pm 2.5> Renewable energy consumption > GHG Emission

Patent applications	Absolute GRG	CO_2 emissions > Mortality from exposure to pm 2.5> Renewable energy consumption > GHG Emission
	Deng's GRG	CO_2 emissions > Mortality from exposure to pm 2.5> Renewable energy consumption > GHG Emission
	SS GRG	CO_2 emissions > Mortality from exposure to pm 2.5> Renewable energy consumption > GHG Emission
Energy consumption	Absolute GRG	Mortality from exposure to pm 2.5> CO_2 emissions > Renewable energy consumption > GHG Emission
	Deng's GRG	CO_2 emissions > Mortality from exposure to pm 2.5> Renewable energy consumption > GHG Emission
	SS GRG	CO_2 emissions > Mortality from exposure to pm 2.5> Renewable energy consumption > GHG Emission
EMS	Absolute GRG	Mortality from exposure to pm 2.5> CO_2 emissions > GHG Emission > Renewable energy consumption
	Deng's GRG	CO_2 emissions > GHG Emission > Renewable energy consumption > Mortality from exposure to pm 2.5
	SS GRG	CO_2 emissions > GHG Emission > Renewable energy consumption > Mortality from exposure to pm 2.5
Population growth	Absolute GRG	CO_2 emissions > Renewable energy consumption > GHG Emission > Mortality from exposure to pm 2.5
	Deng's GRG	Renewable energy consumption > Mortality from exposure to pm 2.5> CO_2 emissions > GHG Emission
	SS GRG	CO_2 emissions > Renewable energy consumption > GHG Emission > Mortality from exposure to pm 2.5

Table 8: Description of goal and decision parameters

Goal	Measuring Grey Relation (Association) between technological innovation, population growth, renewable energy, environmental management systems, and green growth in Pakistan
State of Nature/Criteria (Pj), P = 1, 2…., k	*Patent applications are positively related to green growth.* (P1) *R&D is positively related to green growth* (P2) *EMSs are positively associated with green growth* (P3) *Energy consumption is negatively related to green growth* (P4) *Population growth is negatively related to green growth* (P5)
Alternative Actions (Si), S=1, 2…, m	Grey Relation was superior in GHG emission (S1) Grey Relation was superior in Renewable Energy Consumption (S2) Grey Relation was superior in mortality from exposure to pm 2.5 (S3) Grey Relation was superior in annual CO_2 emissions (S4)

P=5, n=8, outcome = v (S_i , D_j), where i = 1, 2, 3 and j = 1, 2, 3, 4, 5….8. S_1, S_2, S_3 and S_4 show the GRA of technological innovation, energy, environmental management systems, population growth with green growth in Pakistan. The SSDGRA (second synthetic degree of the grey relation-based matrix) is presented in Table 7, which unfolds the relationship between the study factors to arrange the variables and conclude the criteria response. Then a decision-making model is applied to evaluate the impact of technological innovation, energy, environmental management systems, and population growth on green growth in Pakistan, and it is presented in Table 8.

Table 9: SSGRG criteria-based matrix

SSGRG	P_1	P_2	P_3	P4	P5
S_1	0.6049	0.6026	0.4945	0.5602	0.7797
S_2	0.7092	0.6921	0.6923	0.7036	0.7523
S_3	0.8537	0.77462	0.7658	0.6012	0.6850
S_4	0.8561	0.8013	0.7821	0.6241	0.6440

Finally, we applied the Conservative (maximin) model (Ikram, Zhou, Shah, & Liu, 2019) to obtain the optimal solution among all variables for green growth development in Pakistan based on the SSGRG values presented in Table 9. The conservative model shows the following optimal solution:

$$\max L_i \left\{ \min A_k \, v\left(A_p, \mathrm{C}_k\right) \right\} = \max A_p \begin{Bmatrix} 0.4945 \\ 0.6921 \\ 0.6012 \\ 0.6241 \end{Bmatrix} = 0.6921 \textbf{ (Patent Application)}$$

This paper has investigated Pakistan's technological innovation, energy, EMS, population, and economic growth in a multiframework. The study has separately analyzed the potential influence of individual independent variables on dependent variables. Figure 7 shows that patent applications, among all variables, have a significant impact on green growth in Pakistan. Over the years, patent applications have been used as drivers for economic growth. Patent applications can drive sustainability in a country and help abate the environmental crisis (Nitta, 2005). Patent applications are a key indicator of technological innovation (Aghion et al., 2005), help promote renewable energy technology and consumption (Popp, 2012), which lower GHGs and other harmful emissions (Johnstone et al., 2010).

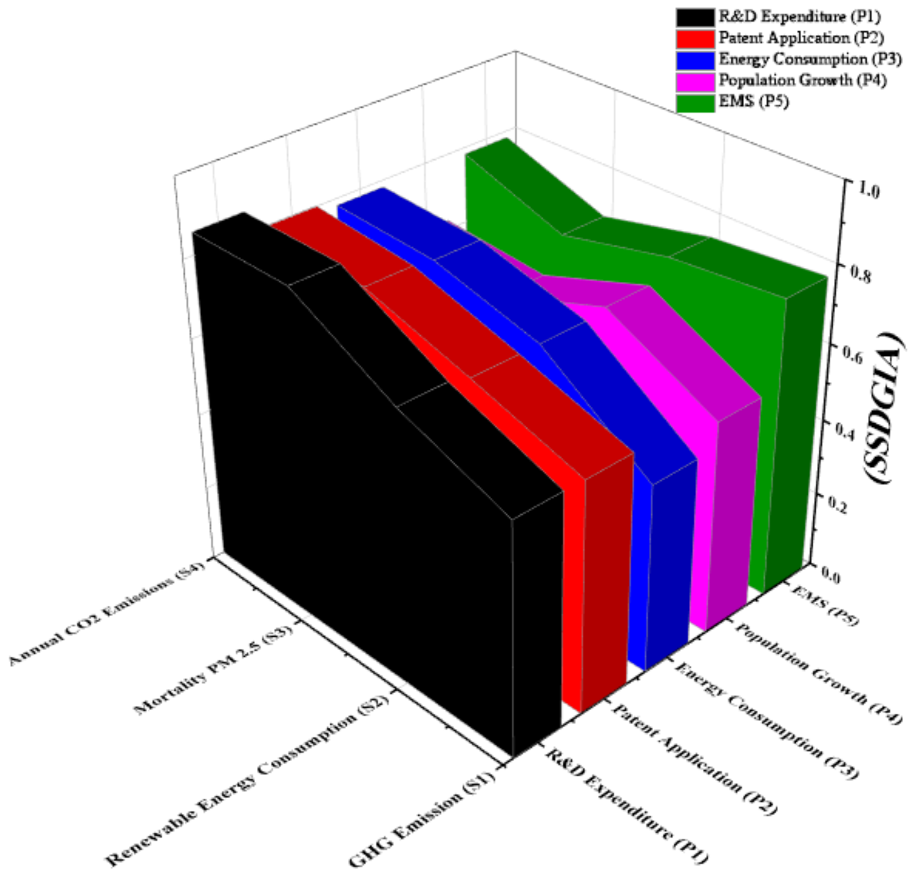

Figure 7: Conservative (Maximin) based evaluation of technological innovation and green growth

5. Conclusion and Policy Implications

5.1 Conclusion

Green growth is pervasive in attaining sustainable development in a country. This paper has explored the dynamic linkage between technological innovation, EMS (seen as a green form of organizational innovation), environmental challenges (namely, energy consumption and population growth), and green growth in the context of Pakistan by using a novel advanced mathematical GRA modeling approach.

Pakistan is a developing country facing acute energy and environmental crisis that needs to be addressed. Despite the excellent potential for renewables, Pakistan has been utilizing fossil fuels combined with traditional technologies to meet the country's economic and social demands. Our results indicate that technological innovation (Patent applications and R&D) are core elements that help develop green growth in Pakistan. R&D and Patent applications are efficient in lowering CO_2 emissions, PM 2.5, and GHG emissions and in promoting renewable energy consumption. Technological innovation helps a country transition from traditional technology to green technology, thus improving environmental performance and boosting production, operation, and process efficiency.

The relationship between energy and green growth shows that energy consumption in factories is a significant cause of the high CO_2 emissions in Pakistan but not directly linked to other GHG emissions in the country. Pakistan is an agricultural country, and other GHG emissions (more than 70%) come from the agricultural sector (Hussain et al., 2019). Energy consumption is also responsible for PM 2.5, an air pollutant having a direct impact on human health. Energy consumption, however, does not exhibit any strong relationship with renewable energy in the country. Although the government has launched initiatives to promote renewable energy on an industrial scale, fossil fuels are still the top choice, which calls for a change in the whole system.

The government must support renewable energy sources and reduce taxes to help industries transition from conventional to alternative energy sources. When we examine the relationship between EMS and green growth, the results show a significant relationship between EMS and CO_2, renewable energy. EMS helps reduce CO_2 and GHG emissions. EMS shares a significant positive relationship with renewable energy, postulating policy implications for Pakistan to implement EMS in order to increase environmental performance. Population growth, however, does not have a meaningful impact on green growth. Despite the existence of an association between the variables, this relationship is not very strong. Results indicate that an increase in population actually causes an increase in CO_2 emissions in Pakistan. The second association was observed between population and renewable energy, which implies that in raising social awareness of environmental protection and preservation, people put pressure on the authorities to protect the environment.

5.2 Policy Implications

Our study offers the following policy implications for stakeholders. First, the government's budget for R&D is not competitive when compared to neighboring developing counties. The Pakistani government must allocate a sufficient budget to R&D as this will help the country boost its technological innovation. The number of national patent applications is also significantly low (The World Bank, 2018), which requires substantial efforts from the government and an effective policy to support locals who want to excel in the technology domain to improve and increase the number of patent applications. The procedure and budget will help local businessmen, technologists, SMEs develop and employ local technology to produce energy from renewables. Technological innovation reduces CO_2 and other emissions and promotes renewable resources and technology to meet national economic demands.

Second, developing countries rely on fossil fuels to meet energy and production demands. It is not easy for a country like Pakistan to shift its industrial operations from fossil fuels to renewables. It requires massive investment in machinery and resource transition. Industries need support to change their operational functions or import technology or technicians in the early stages. The government of Pakistan must take steps to support industries to shift their operations from fossil fuels to renewables, as Pakistan has sufficient renewable potential. The government must attract foreign investors and technology leaders to invest in technological infrastructure and businesses in Pakistan. The goal cannot be achieved by politics alone; substantial efforts, plans, and programs are needed to show the world what this country has to offer, and imports and local taxes should be reduced to support FDI and local industries.

Third, Environmental management systems support green growth progress, but the number of environmental management systems in Pakistan is not promising. State and provincial authorities need to raise awareness of the importance of EMSs within organizations. Pakistan has laws to protect the environment. The government should merge these laws with awareness programs to show the need to adopt environmental management systems in order to protect the environment. Fourth, as a developing country with tight job market and competitive opportunities, it must control the population growth with the help of all levels of government hierarchy.

This study is not without limitations. Since the authors focused on macro-level state factors and variables to track green growth development, the effects of the micro-level sample covering provincial progress towards green growth and organizational level impact have therefore been ignored. Besides technological innovation and environmental challenges, other factors accelerate or hinder green growth development. Therefore, future researchers may consider exploring foreign direct investment, corporate social responsibility, and the institutional relationship with green growth in Pakistan by using advanced econometric techniques at the micro and macro levels. In multiple frameworks, it is hard to include all green growth indicators in one study, so future researchers may explore the dimensions of green growth at the organizational level with a detailed review of Pakistan's circumstances. Green growth is an opportunity to achieve prolonged sustainable development in economic, social, and environmental structures. Hence, an academic from a different field should explore the phenomenon to help the country move forward in a sustainable direction.

Compliance with ethical standards

Ethics approval: Not applicable

Consent to Participate: Not applicable

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References

Abid, N., Ikram, M., Wu, J., & Ferasso, M. (2021). Towards environmental sustainability: Exploring the nexus among ISO 14001, governance indicators and green economy in Pakistan. *Sustainable Production and Consumption*, *27*, 653–666. https://doi.org/10.1016/j.spc.2021.01.024

Abid, N., Wu, J., Ahmad, F., Draz, M. U., Chandio, A. A., & Xu, H. (2020). Incorporating environmental pollution and human development in the energy-growth nexus: A novel long run investigation for Pakistan. *International Journal of Environmental Research and Public Health*, *17*(14), 1–22. https://doi.org/10.3390/ijerph17145154

Acosta, L. A., Maharjan, P., Peyriere, H. M., & Mamiit, R. J. (2020). Natural capital protection indicators: Measuring performance in achieving the Sustainable Development Goals for green growth transition. *Environmental and Sustainability Indicators*, *8*(July), 100069. https://doi.org/10.1016/j.indic.2020.100069

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and Innovation: an Inverted-U Relationship. *The Quarterly Journal of Economics*, *120*(2), 701–728. https://doi.org/10.1093/qje/120.2.701

Aghion, Philippe, Dechezleprêtre, A., Hémous, D., Martin, R., & van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. *Journal of Political Economy*, *124*(1), 1–51. https://doi.org/10.1086/684581

Aghion, Philippe, Dechezleprêtre, A., Hemous, D., Martin, R., & Van Reenen, J. M. (2013). Carbon

Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2202047

Aguilera-Caracuel, J., & Ortiz-de-Mandojana, N. (2013). Green innovation and financial performance: An institutional approach. *Organization and Environment*, *26*(4). https://doi.org/10.1177/1086026613507931

Ahmad, M., Jiang, P., Majeed, A., Umar, M., Khan, Z., & Muhammad, S. (2020). The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: An advanced panel data estimation. *Resources Policy*, *69*(July), 101817. https://doi.org/10.1016/j.resourpol.2020.101817

Alam, M. J., Begum, I. A., Buysse, J., Rahman, S., & Van Huylenbroeck, G. (2011). Dynamic modeling of causal relationship between energy consumption, CO 2 emissions and economic growth in India. *Renewable and Sustainable Energy Reviews*, *15*(6), 3243–3251. https://doi.org/10.1016/j.rser.2011.04.029

Ali Asjad Naqvi & Miriam Rehm. (2014). A multi-agent model of a low income economy: simulating the distributional effects of natural disasters. *Journal of Economic Interaction and Coordination*, *9*, 275–309.

Alkaher, I., & Carmi, N. (2019). Is population growth an environmental problem? Teachers' perceptions and attitudes towards including it in their teaching. *Sustainability (Switzerland)*, *11*(7). https://doi.org/10.3390/su11071994

Apergis, N., & Payne, J. E. (2009). CO2 emissions, energy usage, and output in Central America. *Energy Policy*, *37*(8), 3282–3286. https://doi.org/10.1016/j.enpol.2009.03.048

Aragón-Correa, J. A., & A. Rubio-López, E. (2007). Proactive Corporate Environmental Strategies: Myths and Misunderstandings. *Long Range Planning*, *40*(3), 357–381. https://doi.org/10.1016/j.lrp.2007.02.008

Aravind, D. (2012). Learning and innovation in the context of process-focused management practices: The case of an environmental management system. *Journal of Engineering and Technology Management - JET-M*, *29*(3), 415–433. https://doi.org/10.1016/j.jengtecman.2012.05.001

Arce, M. E., Saavedra, Á., Míguez, J. L., & Granada, E. (2015). The use of grey-based methods in multi-criteria decision analysis for the evaluation of sustainable energy systems: A review. *Renewable and Sustainable Energy Reviews*, *47*, 924–932. https://doi.org/10.1016/j.rser.2015.03.010

Audretsch, D. B., & Belitski, M. (2020). The role of R&D and knowledge spillovers in innovation and productivity. *European Economic Review*, *123*, 103391. https://doi.org/10.1016/j.euroecorev.2020.103391

Avtar, R., Tripathi, S., & Aggarwal, A. K. (2019). *Population – Urbanization – Energy Nexus : A Review*. 1–21.

Badri Ahmadi, H., Hashemi Petrudi, S. H., & Wang, X. (2017). Integrating sustainability into supplier selection with analytical hierarchy process and improved grey relational analysis: a case of telecom industry. *International Journal of Advanced Manufacturing Technology*, *90*(9–12), 2413–2427. https://doi.org/10.1007/s00170-016-9518-z

Bagheri, M., Guevara, Z., Alikarami, M., Kennedy, C. A., & Doluweera, G. (2018). Green growth planning: A multi-factor energy input-output analysis of the Canadian economy. *Energy Economics*, *74*, 708–720. https://doi.org/10.1016/j.eneco.2018.07.015

Bansal, P., & Hunter, T. (2003). Strategic Explanations for the Early Adoption of ISO 14001. *Journal of Business Ethics*, *46*(3), 289–299. https://doi.org/10.1023/A:1025536731830

Barbier, E. B. (2016). Building the Green Economy. *Canadian Public Policy*, *42*(s1), 1–9. https://doi.org/10.3138/cpp.2015-017

Bekun, F. V., Emir, F., & Sarkodie, S. A. (2019). Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. *Science of the Total Environment*, *655*, 759–765. https://doi.org/10.1016/j.scitotenv.2018.11.271

Bellakhal, Rihab & Ben Kheder, Sonia & Haffoudhi, H. (2019). Institutional and market factors driving renewable energy development in MENA region: A panel data approach. *Energy Economics*, *84*(c). https://doi.org/10.1016/j.eneco.2019.104541

Berghäll, E. (2016). Innovation, competition and technical efficiency. *Cogent Business and Management*, *3*(1), 1–23. https://doi.org/10.1080/23311975.2016.1199522

Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy*, *162*, 733–741. https://doi.org/10.1016/j.apenergy.2015.10.104

Boiral, O., & Henri, J. F. (2012). Modelling the impact of ISO 14001 on environmental performance: A comparative approach. *Journal of Environmental Management*, *99*, 84–97. https://doi.org/10.1016/j.jenvman.2012.01.007

Carrillo-Labella, R., Fort, F., & Parras-Rosa, M. (2020). Motives, barriers, and expected benefits of ISO 14001 in the agri-food sector. *Sustainability (Switzerland)*, *12*(5), 1–17. https://doi.org/10.3390/su12051724

Chen, Y., & Lee, C. C. (2020). Does technological innovation reduce CO2 emissions?Cross-country evidence. *Journal of Cleaner Production*, *263*, 121550. https://doi.org/10.1016/j.jclepro.2020.121550

Chiarini, A. (2017). Setting Strategies outside a Typical Environmental Perspective Using ISO 14001 Certification. *Business Strategy and the Environment*, *26*(6), 844–854. https://doi.org/10.1002/bse.1969

Clare D'Souza, Tim Marjoribanks, Suzanne Young, Gillian Sullivan Mort, M. N. & J. J. J. (2019). Environmental management systems: an alternative marketing strategy for sustainability. *Journal of Strategic Marketing*, *27*(5), 417–434. https://doi.org/10.1080/0965254X.2018.1430054

Coccia, M., & Watts, J. (2020). A theory of the evolution of technology: Technological parasitism and the implications for innovation magement. *Journal of Engineering and Technology Management - JET-M*, *55*(December 2019), 101552. https://doi.org/10.1016/j.jengtecman.2019.11.003

Cuerva, M. C., Triguero-Cano, Á., & Córcoles, D. (2014). Drivers of green and non-green innovation: Empirical evidence in Low-Tech SMEs. *Journal of Cleaner Production*, *68*, 104–113. https://doi.org/10.1016/j.jclepro.2013.10.049

Cui, H., Zhao, T., & Wu, R. (2018). CO2 emissions from China's power industry: Policy implications from both macro and micro perspectives. *Journal of Cleaner Production*, *200*, 746–755. https://doi.org/10.1016/j.jclepro.2018.07.330

Curkovic, S., & Sroufe, R. (2011). Using ISO 14001 to promote a sustainable supply chain strategy. *Business Strategy and the Environment*, *20*(2), 71–93. https://doi.org/10.1002/bse.671

da Fonseca, L. M. C. M. (2015). ISO 14001:2015: An improved tool for sustainability. *Journal of Industrial Engineering and Management*, *8*(1), 35–50. https://doi.org/10.3926/jiem.1298

Dai, J., Liu, X., & Hu, F. (2014). Research and application for grey relational analysis in multigranularity based on normality grey number. *The Scientific World Journal*, *2014*. https://doi.org/10.1155/2014/312645

Danish, & Ulucak, R. (2020). How do environmental technologies affect green growth? Evidence from BRICS economies. *Science of the Total Environment*, *712*, 136504. https://doi.org/10.1016/j.scitotenv.2020.136504

Darnall, N. (2006). Why firms mandate ISO 14001 certification. *Business & Society*, *45*, 354–381. https://doi.org/https://doi.org/10.1177/0007650306289387

Darnall, N., Henriques, I., & Sadorsky, P. (2008). Do environmental management systems improve business performance in an international setting? *Journal of International Management*, *14*(4), 364–376. https://doi.org/10.1016/j.intman.2007.09.006

Davis, M., Ahiduzzaman, M., & Kumar, A. (2018). How will Canada's greenhouse gas emissions change by 2050? A disaggregated analysis of past and future greenhouse gas emissions using bottom-up energy modelling and Sankey diagrams. *Applied Energy*, *220*(April), 754–786. https://doi.org/10.1016/j.apenergy.2018.03.064

Di Vita, G. (2017). The international strengthening of IPR and air pollution abatement: the role of the TRIPs agreement. *Technological and Economic Development of Economy*, *23*(2), 316–338. https://doi.org/10.3846/20294913.2015.1072752

Diao, M., Holloway, T., Choi, S., O'Neill, S. M., Al-Hamdan, M. Z., Van Donkelaar, A., Martin, R. V., Jin, X., Fiore, A. M., Henze, D. K., Lacey, F., Kinney, P. L., Freedman, F., Larkin, N. K., Zou, Y., Kelly, J. T., & Vaidyanathan, A. (2019). Methods, availability, and applications of PM2.5 exposure estimates derived from ground measurements, satellite, and atmospheric models. *Journal of the Air and Waste Management Association*, *69*(12), 1391–1414. https://doi.org/10.1080/10962247.2019.1668498

Du, J., Zhang, J., & Li, X. (2020). What is the mechanism of resource dependence and high-quality economic development? An empirical test from China. *Sustainability (Switzerland)*, *12*(19). https://doi.org/10.3390/su12198144

Feng, Y., Ning, M., Lei, Y., Sun, Y., Liu, W., & Wang, J. (2019). Defending blue sky in China: Effectiveness of the "Air Pollution Prevention and Control Action Plan" on air quality improvements from 2013 to 2017. *Journal of Environmental Management*, *252*(August), 109603. https://doi.org/10.1016/j.jenvman.2019.109603

Fernández Fernández, Y., Fernández López, M. A., & Olmedillas Blanco, B. (2018). Innovation for sustainability: The impact of R&D spending on CO2 emissions. *Journal of Cleaner Production*, *172*, 3459–3467. https://doi.org/10.1016/j.jclepro.2017.11.001

Geng, J. (2016). Technological innovation and renewable energy development : Evidence based on patent counts Technological innovation and renewable energy development : evidence based on patent counts Jiang-Bo Geng and Qiang Ji *. *International Journal of Global Environmental Issues*, *15*(3). https://doi.org/10.1504/IJGENVI.2016.076945

Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Economics*, *34*(1), 358–364. https://doi.org/10.1016/j.eneco.2011.06.005

Hao, L. N., Umar, M., Khan, Z., & Ali, W. (2021). Green growth and low carbon emission in G7 countries: How critical the network of environmental taxes, renewable energy and human capital is? *Science of the Total Environment*, *752*, 141853. https://doi.org/10.1016/j.scitotenv.2020.141853

Henriques, I., & Sadorsky, P. (2007). Environmental technical and administrative innovations in the Canadian manufacturing industry. *Business Strategy and the Environment*, *16*(2), 119–132. https://doi.org/10.1002/bse.475

Hussain, M., Butt, A. R., Uzma, F., Ahmed, R., Islam, T., & Yousaf, B. (2019). A comprehensive review of sectorial contribution towards greenhouse gas emissions and progress in carbon capture and storage in Pakistan. *Greenhouse Gases: Science and Technology*, *9*(4), 617–636. https://doi.org/10.1002/ghg.1890

Ikram, M., Zhou, P., Shah, S. A. A., & Liu, G. Q. (2019). Do environmental management systems help improve corporate sustainable development? Evidence from manufacturing companies in Pakistan. *Journal of Cleaner Production*, *226*, 628–641. https://doi.org/10.1016/j.jclepro.2019.03.265

Ikram, Muhammad, Zhang, Q., Sroufe, R., & Shah, S. Z. A. (2020). Towards a sustainable environment: The nexus between ISO 14001, renewable energy consumption, access to electricity, agriculture and CO2 emissions in SAARC countries. *Sustainable Production and Consumption*, *22*, 218–230. https://doi.org/10.1016/j.spc.2020.03.011

International Energy Agency (IEA). (2018). Global Energy & CO2 Status Report The Latest Trends in Energy and Emissions in 2018. https://www.iea.org/geco/

Javed, S.A., Mahmoudi, A. & Khan, A. . (2018). Investigation of drilling parameters on hybrid polymer composites using grey relational analysis, regression, fuzzy logic, and ANN models: a critical note. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *40*(5). https://doi.org/https://doi.org/10.1007/s40430-018-1470-4

Javed, S. A., Khan, A. M., Dong, W., Raza, A., & Liu, S. (2019). Systems evaluation through new grey relational analysis approach: An application on thermal conductivity-petrophysical parameters' relationships. *Processes*, *7*(6), 1–19. https://doi.org/10.3390/pr7060348

Javed, S. A., & Liu, S. (2018). Evaluation of outpatient satisfaction and service quality of Pakistani healthcare projects: Application of a novel synthetic grey incidence analysis model. *Grey Systems: Theory and Application*, *8*(4), 462–480.

Javed, S. A., & Liu, S. (2017). Evaluation of project management knowledge areas using grey incidence model and AHP. *2017 International Conference on Grey Systems and Intelligent Services (GSIS)*, 120–120. https://doi.org/10.1109/GSIS.2017.8077684

Jens, Horbach, P., Rennings, K. (2008). What triggers environmental management and innovation? Empirical evidence for Germany. *Ecological Economics*, *66*(1), 153–160. https://doi.org/10.1016/j.ecolecon.2007.08.016

Johnstone, N., Haščič, I., & Popp, D. (2010). Renewable energy policies and technological innovation: Evidence based on patent counts. *Environmental and Resource Economics*, *45*(1), 133–155. https://doi.org/10.1007/s10640-009-9309-1

Ju-Long, D. (1982). Control problems of grey systems. *Systems and Control Letters*, *1*(5), 288–294. https://doi.org/10.1016/S0167-6911(82)80025-X

Jung, S., An, K. J., Dodbiba, G., & Fujita, T. (2012). Regional energy-related carbon emission characteristics and potential mitigation in eco-industrial parks in South Korea: Logarithmic mean Divisia index analysis based on the Kaya identity. *Energy*, *46*(1), 231–241.

https://doi.org/10.1016/j.energy.2012.08.028

Kammerer, D. (2009). The effects of customer benefit and regulation on environmental product innovation. Empirical evidence from appliance manufacturers in Germany. *Ecological Economics*, *68*(8–9), 2285–2295. https://doi.org/10.1016/j.ecolecon.2009.02.016

Kang, S. J. (2015). Green growth and sustainable development in G20: Performance and prospects. *The International Monetary System, Energy and Sustainable Development*, *138*, 273–293. https://doi.org/10.4324/9781315732275

Kantor, I., Fowler, M. W., Hajimiragha, A., & Elkamel, A. (2010). Air quality and environmental impacts of alternative vehicle technologies in Ontario, Canada. *International Journal of Hydrogen Energy*, *35*(10), 5145–5153. https://doi.org/10.1016/j.ijhydene.2009.08.071

Köne, A. I., & Büke, T. (2010). Forecasting of CO2 emissions from fuel combustion using trend analysis. In *Renewable and Sustainable Energy Reviews* (Vol. 14, Issue 9, pp. 2906–2915). https://doi.org/10.1016/j.rser.2010.06.006

Konnola, T., & Unruh, G. C. (2007). Really Changing the Course : the. *Business Strategy & the Environment*, *537*(April 2005), 525–537. 10.1002/bse.487%5Cnhttp://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=27438533&site=ehost-live

Kunapatarawong, R., & Martínez-Ros, E. (2016). Towards green growth: How does green innovation affect employment? *Research Policy*, *45*(6), 1218–1232. https://doi.org/10.1016/j.respol.2016.03.013

Laskurain, I., Ibarloza, A., Larrea, A., & Allur, E. (2017). Contribution to energy management of the main standards for environmental management systems: The case of ISO 14001 and EMAS. *Energies*, *10*(11). https://doi.org/10.3390/en10111758

Latif, S., Shahid, M., Mahmood, H., & Shahbaz, M. (2014). *Coal consumption : An alternate energy resource to fuel economic growth in Pakistan*. *36*, 282–287. https://doi.org/10.1016/j.econmod.2013.09.046

Li, X., Du, J., & Long, H. (2019a). Green development behavior and performance of industrial enterprises based on grounded theory study: Evidence from China. *Sustainability (Switzerland)*, *11*(15), 1–19. https://doi.org/10.3390/su11154133

Li, X., Du, J., & Long, H. (2019b). Theoretical framework and formation mechanism of the green development system model in China. *Environmental Development*, *32*(October), 100465. https://doi.org/10.1016/j.envdev.2019.100465

Li, X., Du, J., & Long, H. (2020). Mechanism for green development behavior and performance of industrial enterprises (Gdbp-ie) using partial least squares structural equation modeling (pls-sem). *International Journal of Environmental Research and Public Health*, *17*(22), 1–19. https://doi.org/10.3390/ijerph17228450

Li, X., & Long, H. (2020). Research focus, frontier and knowledge base of green technology in China: Metrological research based on mapping knowledge domains. *Polish Journal of Environmental Studies*, *29*(5), 3003–3011. https://doi.org/10.15244/pjoes/114500

Liu, S., Zhang, H., & Yang, Y. (2017). Explanation of terms of grey incidence analysis models. *Grey Systems: Theory and Application*, *7*(1), 136–142.

Mazzi, A., Toniolo, S., Catto, S., De Lorenzi, V., & Scipioni, A. (2017). The combination of an

Environmental Management System and Life Cycle Assessment at the territorial level. *Environmental Impact Assessment Review*, *63*, 59–71. https://doi.org/10.1016/j.eiar.2016.11.004

Mensah, C. N., Long, X., Boamah, K. B., Bediako, I. A., Dauda, L., & Salman, M. (2018). The effect of innovation on CO2 emissions of OCED countries. *Environmental Science and Pollution Research*, *25*(29), 29678–29698. https://doi.org/10.1007/s11356-018-2968-0

Merino-Saum, A., Clement, J., Wyss, R., & Baldi, M. G. (2020). Unpacking the Green Economy concept: A quantitative analysis of 140 definitions. *Journal of Cleaner Production*, *242*, 118339. https://doi.org/10.1016/j.jclepro.2019.118339

Miao, L. (2017). Examining the impact factors of urban residential energy consumption and CO2 emissions in China – Evidence from city-level data. *Ecological Indicators*, *73*, 29–37. https://doi.org/10.1016/j.ecolind.2016.09.031

Mungai, E. M., Ndiritu, S. W., & Rajwani, T. (2020). Do voluntary environmental management systems improve environmental performance? Evidence from waste management by Kenyan firms. *Journal of Cleaner Production*, *265*, 121636. https://doi.org/10.1016/j.jclepro.2020.121636

Naveh, E., Meilich, O., & Marcus, A. (2006). The effects of administrative innovation implementation on performance: An organizational learning approach. *Strategic Organization*, *4*(3), 275–302. https://doi.org/10.1177/1476127006066969

Nitta, I. (2005). Proposal for A Green Patent System: Implications for Sustainable Development and Climate Change. *Sustainable Development Law & Policy*, *5*(2), 61–65.

Odeh, N. A., & Cockerill, T. T. (2008). Life cycle GHG assessment of fossil fuel power plants with carbon capture and storage. *Energy Policy*, *36*(1), 367–380. https://doi.org/10.1016/j.enpol.2007.09.026

OECD Green Growth stduies. (2011). *Towards Green Growth: A Summary for Policy Maker*. https://www.oecd.org/env/towards-green-growth-9789264111318-en.htm

Osobajo, O. A., Otitoju, A., Otitoju, M. A., & Oke, A. (2020). The impact of energy consumption and economic growth on carbon dioxide emissions. *Sustainability (Switzerland)*, *12*(19), 1–16. https://doi.org/10.3390/SU12197965

Popp, D. (2012). The Role of Technological Change in Green Growth. *World Bank Policy Research Working Paper*, *6239*. https://doi.org/10.3386/w18506

Raines, S. S. (2002). Implementing ISO 14001 - An international survey assessing the benefits of certification. *Corporate Environmental Strategy*, *9*(4), 418–426. https://doi.org/10.1016/S1066-7938(02)00009-X

Ramanujam, R., Muthukrishnan, N., & Raju, R. (2011). Optimization of cutting parameters for turning Al-SiC(10p) MMC using ANOVA and Grey relational analysis. *International Journal of Precision Engineering and Manufacturing*, *12*(4), 651–656. https://doi.org/10.1007/s12541-011-0084-x

Rehman, E., Ikram, M., Feng, M. T., & Rehman, S. (2020). Sectoral-based CO2 emissions of Pakistan: a novel Grey Relation Analysis (GRA) approach. *Environmental Science and Pollution Research*, *27*(23), 29118–29129. https://doi.org/10.1007/s11356-020-09237-7

Roberts, G., & Wooster, M. J. (2021). Global impact of landscape fire emissions on surface level PM2.5 concentrations, air quality exposure and population mortality. *Atmospheric Environment*, 118210. https://doi.org/10.1016/j.atmosenv.2021.118210

Rosa, E. A., & Dietz, T. (2012). Human drivers of national greenhouse-gas emissions. *Nature Climate Change*, *2*(8), 581–586. https://doi.org/10.1038/nclimate1506

Ruggieri, M., & Plaia, A. (2012). An aggregate AQI: Comparing different standardizations and introducing a variability index. *Science of the Total Environment*, *420*, 263–272. https://doi.org/10.1016/j.scitotenv.2011.09.019

Rusko, M., Sablik, J., Marková, P., Lach, M., & Friedrich, S. (2014). Sustainable development, quality management system and environmental management system in Slovak Republic. *Procedia Engineering*, *69*, 486–491. https://doi.org/10.1016/j.proeng.2014.03.016

Samargandi, N. (2017). Sector value addition, technology and CO 2 emissions in Saudi Arabia. *Renewable and Sustainable Energy Reviews*, *78*(April), 868–877. https://doi.org/10.1016/j.rser.2017.04.056

Sandberg, M., Klockars, K., & Wilén, K. (2019). Green growth or degrowth? Assessing the normative justifications for environmental sustainability and economic growth through critical social theory. *Journal of Cleaner Production*, *206*, 133–141. https://doi.org/10.1016/j.jclepro.2018.09.175

Sarikaya, M., & Güllü, A. (2015). Multi-response optimization of minimum quantity lubrication parameters using Taguchi-based grey relational analysis in turning of difficult-to-cut alloy Haynes 25. *Journal of Cleaner Production*, *91*, 347–357. https://doi.org/10.1016/j.jclepro.2014.12.020

Sato, Y. (2007). Energy consumption: An environmental problem. *IEEJ Transactions on Electrical and Electronic Engineering*, *2*(1), 12–16. https://doi.org/10.1002/tee.20109

Schiederig, T., Tietze, F., & Herstatt, C. (2012). Green innovation in technology and innovation management - an exploratory literature review. *R and D Management*, *42*(2), 180–192. https://doi.org/10.1111/j.1467-9310.2011.00672.x

Shahzad, S. J. H., Kumar, R. R., Zakaria, M., & Hurr, M. (2017). Carbon emission, energy consumption, trade openness and financial development in Pakistan: A revisit. *Renewable and Sustainable Energy Reviews*, *70*(November 2015), 185–192. https://doi.org/10.1016/j.rser.2016.11.042

Shaikh, I. A., & Colarelli O'Connor, G. (2020). Understanding the motivations of technology managers in radical innovation decisions in the mature R&D firm context: An Agency theory perspective. *Journal of Engineering and Technology Management - JET-M*, *55*(December 2019). https://doi.org/10.1016/j.jengtecman.2020.101553

Shi, K., & Wu, L. (2020). Forecasting air quality considering the socio-economic development in Xingtai. *Sustainable Cities and Society*, *61*(May), 102337. https://doi.org/10.1016/j.scs.2020.102337

Shrestha, R. M., & Shrestha, R. M. (2013). *Linked references are available on JSTOR for this article : Supplemental data for " Energy use and greenhouse gas emissions in selected Hindu Kush – Himalayan countries " by*. *33*(3), 33–35.

Smith, K. R., Frumkin, H., Balakrishnan, K., Butler, C. D., Chafe, Z. A., Fairlie, I., Kinney, P., Kjellstrom, T., Mauzerall, D. L., McKone, T. E., McMichael, A. J., & Schneider, M. (2013). Energy and human health. *Annual Review of Public Health*, *34*, 159–188. https://doi.org/10.1146/annurev-publhealth-031912-114404

Sohn, S. Y., Jeon, J., & Han, E. J. (2015). A new cost of ownership model for the acquisition of technology complying with environmental regulations. *Journal of Cleaner Production*, *100*, 269–277. https://doi.org/10.1016/j.jclepro.2015.03.057

Song, X., Zhou, Y., & Jia, W. (2019). How do Economic Openness and R&D Investment Affect Green

Economic Growth?—Evidence from China. *Resources, Conservation and Recycling*, *146*(December 2018), 405–415. https://doi.org/10.1016/j.resconrec.2019.03.050

Stoknes, P. E., & Rockström, J. (2018). Redefining green growth within planetary boundaries. *Energy Research and Social Science*, *44*(April), 41–49. https://doi.org/10.1016/j.erss.2018.04.030

Su, C. W., Naqvi, B., Shao, X. F., Li, J. P., & Jiao, Z. (2020). Trade and technological innovation: The catalysts for climate change and way forward for COP21. *Journal of Environmental Management*, *269*(March), 110774. https://doi.org/10.1016/j.jenvman.2020.110774

Sulaiman, C., & Abdul-Rahim, A. S. (2018). Population Growth and CO2 Emission in Nigeria: A Recursive ARDL Approach. *SAGE Open*, *8*(2). https://doi.org/10.1177/2158244018765916

Tambovceva, T., & Geipele, I. (2012). Environmental management systems experience among Latvian construction companies. *Technological and Economic Developement of Economy*, *17*(4), 595–610. https://doi.org/https://doi.org/10.3846/20294913.2011.603179

Testa, F., Rizzi, F., Daddi, T., Gusmerotti, N. M., Frey, M., & Iraldo, F. (2014). EMAS and ISO 14001: The differences in effectively improving environmental performance. *Journal of Cleaner Production*, *68*, 165–173. https://doi.org/10.1016/j.jclepro.2013.12.061

The world bank. (2018). *Patent applications, Pakistan*. https://data.worldbank.org/indicator/IP.PAT.RESD?locations=PK

Tseng, M. L., Wang, R., Chiu, A. S. F., Geng, Y., & Lin, Y. H. (2013). Improving performance of green innovation practices under uncertainty. *Journal of Cleaner Production*, *40*, 71–82. https://doi.org/10.1016/j.jclepro.2011.10.009

Tugcu, C. T., Ozturk, I., & Aslan, A. (2012). Renewable and non-renewable energy consumption and economic growth relationship revisited: Evidence from G7 countries. *Energy Economics*, *34*(6), 1942–1950. https://doi.org/10.1016/j.eneco.2012.08.021

Umar, M., Ji, X., Kirikkaleli, D., Shahbaz, M., & Zhou, X. (2020). Environmental cost of natural resources utilization and economic growth: Can China shift some burden through globalization for sustainable development? *Sustainable Development*, *28*(6), 1678–1688. https://doi.org/10.1002/sd.2116

Vazquez-Brust, D., Smith, A. M., & Sarkis, J. (2014). Managing the transition to critical green growth: The "Green Growth State." *Futures*, *64*, 38–50. https://doi.org/10.1016/j.futures.2014.10.005

Vo, D. H., & Vo, A. T. (2021). Renewable energy and population growth for sustainable development in the Southeast Asian countries. *Energy, Sustainability and Society*, *11*(1), 1–15. https://doi.org/10.1186/s13705-021-00304-6

Wagner, M. (2010). The role of corporate sustainability performance for economic performance: A firm-level analysis of moderation effects. *Ecological Economics*, *69*(7), 1553–1560. https://doi.org/10.1016/j.ecolecon.2010.02.017

Wakeel, M., Chen, B., & Jahangir, S. (2016). Overview of energy portfolio in Pakistan. *Energy Procedia*, *88*, 71–75. https://doi.org/10.1016/j.egypro.2016.06.024

Walker, R. M., Damanpour, F., & Devece, C. A. (2011). Management innovation and organizational performance: The mediating effect of performance management. *Journal of Public Administration Research and Theory*, *21*(2), 367–386. https://doi.org/10.1093/jopart/muq043

Wang, K. H., Umar, M., Akram, R., & Caglar, E. (2021). Is technological innovation making world

"Greener"? An evidence from changing growth story of China. *Technological Forecasting and Social Change*, *165*(July 2020), 120516. https://doi.org/10.1016/j.techfore.2020.120516

Wang, X., & Shao, Q. (2019). Non-linear effects of heterogeneous environmental regulations on green growth in G20 countries: Evidence from panel threshold regression. *Science of the Total Environment*, *660*, 1346–1354. https://doi.org/10.1016/j.scitotenv.2019.01.094

Wang, Y., Liu, X., Sun, X., & Wang, B. (2020). Energy saving, GHG abatement and industrial growth in OECD countries: A green productivity approach. *Energy*, *194*, 116833. https://doi.org/10.1016/j.energy.2019.116833

Wang, Z., & Zhu, Y. (2020). Do energy technology innovations contribute to CO2 emissions abatement? A spatial perspective. *Science of the Total Environment*, *726*, 138574. https://doi.org/10.1016/j.scitotenv.2020.138574

World health Organization. (2020). *Environmental health*. World Health Organization, Regional Office for Eastern Mediterranean. http://www.emro.who.int/pak/programmes/environmental-health.html

Wu, W. (2017). Institutional Quality and Air Pollution: International Evidence. *International Journal of Business and Economics*, *16*(1), 49–74.

Xu, J., & Li, Y. (2018). Grey incidence analysis model of classification variables and its application on innovation & entrepreneurship education in Jiangsu. *Journal of Grey System*, *30*(1), 123–128.

Xu, Y., Du, J., Shahzad, F., & Li, X. (2021). Untying the Influence of Green Brand Authenticity on Electronic Word-of-Mouth Intention: A Moderation–Mediation Model. *Frontiers in Psychology*, *12*(September). https://doi.org/10.3389/fpsyg.2021.724452

Zhai, X., & An, Y. (2021). The relationship between technological innovation and green transformation efficiency in China: An empirical analysis using spatial panel data. *Technology in Society*, *64*(September 2020), 101498. https://doi.org/10.1016/j.techsoc.2020.101498

Zhang, M., Ding, S., Pang, J., & Wang, W. (2021). The effect of indirect household energy consumption on PM 2.5 emission in China: An analysis based on CLA method. *Journal of Environmental Management*, *279*(April 2020), 111531. https://doi.org/10.1016/j.jenvman.2020.111531

Zhang, S., Hu, T., Li, J., Cheng, C., Song, M., Xu, B., & Baležentis, T. (2019). The effects of energy price, technology, and disaster shocks on China's Energy-Environment-Economy system. *Journal of Cleaner Production*, *207*, 204–213. https://doi.org/10.1016/j.jclepro.2018.09.256

Zhicai, Z., & Li, C. (2018). Analysis on decision-making model of plan evaluation based on grey relation projection and combination weight algorithm. *Journal of Systems Engineering and Electronics*, *29*(4), 789–796.

Ziegler, A., & Seijas Nogareda, J. (2009). Environmental management systems and technological environmental innovations: Exploring the causal relationship. *Research Policy*, *38*(5), 885–893. https://doi.org/10.1016/j.respol.2009.01.020