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Exploring the Role of Technological Progress in Reducing Carbon Emissions

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A B S T R A C T

China is striving to reduce carbon dioxide emissions by 2030 and reach net zero by 2060, and technological progress plays a special role in this regard. Since China announced its goal of minimizing carbon dioxide emissions before 2030 and ending carbon production before 2060, it has tried to achieve this goal by taking various measures. Among all these measures, progress in science and technology is crucial to provide a strong impetus and long-term momentum for the country. China has taken nationwide measures to phase out and upgrade old fuel facilities to reduce air pollution and carbon dioxide emissions, and in practice, CO_2 emissions from combustion have been significantly reduced by using more efficient catalysts and better industrial processes. According to a study reported by Gauging Daily, from 2013 to 2020, China's measures to create clean air, use green energy and reduce CO_2 emissions have reduced carbon dioxide production by 2.43 billion tons. These measures have saved a total of 1.06 billion tons of standard coal. In 2020 alone, clean air measures saved 247 million tons of standard coal and reduced 570 million tons of carbon dioxide, accounting for 5.5 percent of China's total CO_2 emissions that year. Supported by advanced technologies, chemical plants in China have reduced their carbon emissions. In Shanghai, east China, there is already a refinery that produces carbon-free products. Gaoqiao Petrochemical, a subsidiary of Sinopec in Shanghai, delivered the first batch of carbon-free refinery products made from 30,000 tons of crude oil, including gasoline, diesel, kerosene and liquefied petroleum gas, all of which are carbon-neutral and have Environment Shronang certification. The refinery completed 53 pollution control projects between 2018 and 2020, which significantly reduced the total emission of major pollutants. The average carbon emission concentration in the sector has been reduced to 23% of the standard level. In 2021, projects such as colored smoke treatment, volatile organic compound treatment and ultra-low carbon emission heating furnace modification were launched to further reduce carbon dioxide emissions.

Introduction

Reducing the use of fossil fuels such as gasoline and coal and increasing the use of clean energy also play a significant role in this issue. Chinese automaker Geely delivered methanol hybrid sedans to the market in Jinzhong City, Shanxi at the end of August this year. Research development has solved the corrosion effect of methanol on rubber products and non-ferrous metal materials, and automakers have made breakthroughs in core technologies such as the use of methanol fuel.

The vehicle's operating cost per kilometer is only 0.3 yuan (about 0.04 US dollars), and its carbon emissions can be reduced by 8 tons per 10,000 kilometers. Geely's methanol sedan and heavy truck also went to Denmark for testing in March this year. This was the first time such vehicles were used in the European country. According to the China National Energy Administration, the share of coal consumption in China fell from 65.8% in 2014 to 56% in 2021, the fastest decline in history. Meanwhile, the share of clean energy consumption

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rose from 16.9% to 25.5% over the same period, accounting for more than 60% of the increase in energy consumption.

More carbon absorption

In addition to reducing emissions, CO_2 capture and utilization is another way to reduce the impact of greenhouse gases. On August 29, 2022, Sinopec announced the completion of China's largest CO_2 capture, utilization and storage project. This is China's first million-ton scale project for such a purpose, which can reduce CO_2 emissions by 1 million tons per year, equivalent to planting nearly 9 million trees. CO_2 capture, utilization and storage can achieve a win-win situation of increasing oil production and reducing carbon emissions. "This is a new technology for the low-carbon and efficient development of fossil energy," said Ma Yongsheng, chairman of Sinopec. According to him, Sinopec captured 1.52 million tons of CO_2 in 2021. During the 14th Five-Year Plan period (2021-2025), the company plans to build two more pilot projects for CO_2 capture, utilization and storage in its oil fields. The latest developments in chemical synthesis have made CO_2 a raw material for chemical products. According to a report published by Science and Technology Daily in July, researchers from the Institutes of Physical Sciences under the Chinese Academy of Sciences have found a copper nanocrystal that can catalyze the production of liquid alcohols from CO_2. According to the study, the reaction can use electrical energy to convert CO_2 into desired products with a catalyst, while simultaneously reducing CO_2 in the air. Recent advances also include a method for synthesizing starch from CO_2, the first of its kind in the world, a method for producing protein using industrial exhaust gases containing CO_2, CO and ammonia water, and a method for producing formic acid from CO_2 and water.

Ternary metal sulfides as electro catalysts for carbon dioxide reduction reactions

One of the most promising ways to actively reduce the level of CO_2 in the atmosphere is to recycle it into valuable chemicals through electro catalytic CO_2 reduction reactions. With a suitable electro catalyst, this can be achieved under mild conditions and at low energy cost. Many types of electro catalysts are actively being investigated, but most of them suffer from low electro catalytic activity, poor selectivity, or low stability. Metal sulfides may hold a huge potential solution to this puzzle. Combining ionic and covalent properties, this unique family of materials offers good catalytic activity and energy efficiency. The ternary metal system is expected to be a better solution because, according to recent studies, simple metal sulfides can still produce only a few simple carbon compounds in CO_2 reduction reactions. Therefore, they lack versatility. However, there are still very few publications discussing the performance of ternary metal sulfide as a CO_2 reduction electro catalyst. Against this backdrop, a research team led by Assistant Professor Akira Yamaguchi from the Tokyo Institute of Technology, Japan, has undertaken an effort to study the process of ternary metal sulfides that has not been reported elsewhere. In their latest study, published in Science and Engineering: R: Reports, they combined experimental data analysis and machine learning to gain insight into this uncharted territory in materials science. "Ternary metal sulfides may offer synergistic bimetallic effects that enhance CO_2 reduction performance. However, these materials have complex electronic structures, and it is difficult to use their adsorption energy for intermediate compounds to analyze the process of electro catalyst performance of various metals and alloys," explains Yamaguchi. To overcome these challenges, the researchers developed a new screening method. Unlike previous screening methods that often involve computationally expensive calculations of electro catalyst adsorption energies, the researchers focused on analyzing measurable and more easily calculable material properties from experiments and data analysis. Using experimental data obtained from various measurements of their synthesized metal sulfide samples, the researchers calculated a set of material properties that represent structural, volumetric, and surface parameters.

They also measured the electrochemical CO_2 reduction activity of the materials. In addition, they used four high-dimensional regression algorithms in machine learning models to uncover possible relationships between material properties and electro catalytic performance. In this way, the researchers devised a simple workflow that can identify important parameters to explain the origin of high activity in electro catalytic materials. One of the main findings of the study was that focusing on the crystal structure of ternary metal sulfides leads to better results than focusing solely on their elemental composition. "Our approach is more robust than other screening techniques and does not require high-throughput experimental tools. Furthermore, it is generalizable and applicable to many materials, making it particularly useful given the limited availability of material activity data for CO_2 reduction reactions." Yamaguchi explains. The research team hopes that their efforts will lead to effective design guidelines for developing CO_2 conversion catalysts using materials that are ubiquitous in nature, as well as the potential application of their guidelines to other research areas.

Economic opportunities for carbon capture

Another promising application of CCU is in the field of synthetic fuels. Companies such as Carbon Engineering have developed technologies that capture CO_2 from the air and convert it into synthetic fuels such as gasoline and diesel. This process, known as direct air capture (DAC), offers a renewable alternative to fossil fuels while simultaneously removing CO_2 from the atmosphere. Beyond construction and fuel production, CCU technologies are also being explored in the manufacturing sector. Some companies use the captured CO_2 to produce chemicals and polymers that are essential components in various industrial processes. By incorporating captured carbon into these products, companies not only reduce their carbon emissions but also create a market for sustainable materials.

A Paradigm Shift

The transition from carbon capture and storage (CCS) to carbon capture and utilization (CCU) represents a paradigm shift in how society approaches carbon emissions. Rather than seeing CO_2 as a waste product, CCU technologies recognize its potential as a valuable resource. This shift is supported by advances in technology and a growing awareness of the need for sustainable practices across industries, yet there are significant challenges in scaling up CCU technologies to achieve widespread adoption. Issues such as affordability, regulatory frameworks and public understanding are significant barriers that must be overcome to fully realize the potential of CCU. Governments, businesses and research institutions have a key role to play in overcoming these challenges and driving innovation in carbon utilization. Looking ahead, the integration of CCU into mainstream industries holds promise for a more sustainable future. By using captured carbon in manufacturing, construction and energy production, society can reduce its dependence on fossil fuels and control the impacts of climate change. As technologies continue to advance and awareness increases, the potential for CCU to play a pivotal role in the transition to a low-carbon economy is increasingly apparent, making carbon capture and use a forward-looking approach to addressing climate change. By going beyond storing and converting captured carbon into valuable products, companies are not only reducing their own environmental footprint, but also paving the way for a more sustainable and economic future. As these technologies evolve and expand, they have the potential to transform industries and contribute to global efforts to achieve a greener planet. A low-carbon economy is an economic system that aims to minimize emissions of carbon dioxide and other greenhouse gases (GHGs), ultimately promoting environmental sustainability. This type of economy involves a transition from traditional fossil fuel-based energy systems to renewable energy sources, increasing energy efficiency, and fostering sustainable practices across sectors. Achieving a low-carbon economy requires a multifaceted approach that includes policy measures, technological innovations, and social change.

Key Components

Renewable energy is a key component of a low-carbon economy. Investment in solar and wind energy infrastructure can significantly reduce dependence on fossil fuels. These sources of energy are clean, sustainable and virtually inexhaustible. Hydropower and biomass can also help reduce carbon emissions, provided they are managed sustainably. Increasing insulation, using energy-efficient appliances and implementing smart energy management systems in buildings can also reduce energy consumption. Upgrading industrial processes and equipment to be more energy efficient can lead to significant reductions in carbon emissions. Implementing carbon capture schemes at emission sources, such as power plants and industrial facilities, can prevent CO_2 from entering the atmosphere. Promoting the use of electric vehicles and developing the necessary charging infrastructure can reduce greenhouse gas emissions in the transport sector. Expanding public transport systems and encouraging walking and cycling have been able to reduce carbon footprints in some European countries. Implementing comprehensive recycling programmers and encouraging the reuse of waste can reduce and minimize greenhouse gas emissions associated with production processes. Protecting existing forests and restoring degraded land can absorb CO_2 from the atmosphere.

The ways to achieve a low-carbon economy can be summarized as follows

- ✓ **Carbon pricing policy and regulation:** Implementing carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can provide incentives to reduce emissions.
- ✓ **Regulatory standards:** Establishing strict emission standards and efficiency requirements for industries, buildings and vehicles can lead to the adoption of low-carbon technologies.

Fiscal incentives

- ✓ **Subsidies and grants:** Providing financial support for renewable energy projects, promoting energy efficiency and sustainable practices can accelerate the transition to a low-carbon economy.
- ✓ **Green bonds and investment:** Encouraging investment in green technologies and infrastructure through financial instruments such as green bonds can mobilize the necessary capital.

Research and innovation

- **Technology development:** Investing in research and development of new technologies that can reduce greenhouse gas emissions and increase sustainability is crucial.
- **Collaboration and knowledge sharing:** Promoting collaboration between governments, industry and universities can facilitate knowledge exchange and accelerate innovation.

Public awareness and participation

- **Educational campaigns:** Raising awareness about the benefits of a low-carbon economy and encouraging sustainable practices among individuals and businesses can drive collective action.
- **Community initiatives:** Supporting community-led initiatives that promote energy conservation, renewable energy adoption, and sustainable living can foster grassroots change.

International cooperation

- **Global agreements:** Participating in international agreements, such as the Paris Agreement, and committing to national greenhouse gas emission reduction targets can enhance global efforts to mitigate climate change.
- **Technology transfer:** Facilitating the transfer of low-carbon technologies to developing countries can support global emission reduction goals and promote sustainable development. In short, the transition to a low-carbon economy is a complex but necessary effort to combat climate change and ensure a sustainable future. By using renewable energy, increasing energy efficiency, promoting sustainable transport, adopting circular economy practices, and supporting reforestation, we can significantly reduce carbon emissions. Achieving this transition requires coordinated efforts across policy, finance, innovation, public participation and international cooperation. With the right strategies and collective action, a low-carbon economy is not only achievable, but also beneficial for the environment, the economy and society.

Factors influencing changes in carbon dioxide emissions

Economic progress around the world has led to various changes; For example, hundreds of millions of jobs have been created, improvements in life support and health, access to goods and a wide range of foods, etc., which are especially significant in emerging economies. The basis of all these advances in industrialization, globalization, market expansion, etc. is the energy sector, and energy consumption has had profound effects on the economic growth of societies. The need for energy for economic activities and the needs of the growing population have led to an increase in its consumption in recent years. According to a 2014 World Bank report, per capita carbon dioxide emissions in the world were 5 metric tons, and the growth rate of this gas emission during the years 1990-2014 was about 19 percent. The per capita carbon dioxide emissions for Iran in 2014 were 8.4 metric tons, and the growth of its emissions during 1990-2014 was about 127 percent, which is more than double the growth (World Bank, 2014). This indicates the undesirable level of emissions and the inadequate environmental conditions as one of the most important factors in achieving sustainable development.

Although energy consumption is necessary for the economic progress of societies, its increasing consumption has also led to environmental problems, the most important of which is air pollution due to the emission and leakage of gases resulting from the combustion of fossil fuels. According to the definition of air quality standards, the presence and distribution of one or more pollutants, including solids, liquids, gases, radioactive and non-radioactive radiation in the open air in an amount and for a period that makes air quality harmful to humans and the environment is called air pollution. Carbon monoxide, nitrogen oxides, hydrocarbons, sulfur oxides, carbon dioxide, particulate matter, and ozone are the most important air pollutants. Among the greenhouse gases, carbon dioxide is the most important. About 60 percent of the greenhouse effects caused by human activity are related to carbon dioxide emissions. In many studies conducted in this field, the emission rate of this gas has been used as a measure of air pollution.

Air pollution is a major threat to health and climate, and has brought about climate change and global warming; this warming has both caused severe weather disasters and jeopardized sustainable economic and social development. A report by the Intergovernmental Panel on Climate Change (IPCC) has pointed out that the increase in carbon dioxide (CO_2) emissions from fossil fuel consumption is the main cause of global climate change. Many studies have used decomposition analysis methods to examine energy consumption or energy intensity. Grossman and Krueger (1992) decomposed the environmental impacts of the North American Free Trade Agreement (NAFTA) in terms of changes in pollution emissions due to the effects of scale, composition, and technique. The pollution coefficient (the ratio of pollution to output), energy intensity (the ratio of energy to output), economic structure or the share of production sectors in total economic output, and economic growth (GDP) are

considered as the main components of decomposition analysis. Ng and Parikh (2000) used the index decomposition method to show that the income effect is the most important determinant of the increase in per capita emissions in India.
Also, studies by Zhang and Ng (2001), Paul and Bhattacharya (2004), Li and Oh (2006), Liaskes et al. (2000), Wang et al. (2013) have been conducted to decompose energy intensity and its environmental impacts using the decomposition analysis method.
Siri and Svetas (2004) have used the variance decomposition method of prediction error to determine the relationship between energy consumption and economic growth in Turkey. Weitz (2006) has studied carbon emissions and the factors affecting them in Turkey using the IDA method.
Relatively many studies have been conducted to analyze energy consumption and CO_2 emissions in China. Fan et al. (2007) analyzed changes in carbon intensity based on the arithmetic mean index (AMDI). Structural analysis method was used to investigate the factors of CO_2 emission in China during 1980-2030 by Gan et al. (2008). Based on the logarithmic mean index (LMDI) of the time series, Liu et al. (2007) investigated the carbon emission change of 36 industrial sectors during 1998-2005. Wang et al. (2005) applied the LMDI method to energy-related CO_2 emission. Wu et al. (2005) investigated the change of energy-related CO_2 emission during 1985-1999 using the index decomposition method. Ang et al. (2015) investigated the energy efficiency of industrial countries based on the logarithmic index.
Changes in CO_2 emissions in Iran have been analyzed in terms of four main factors: energy intensity, pollution coefficient, structural changes, and economic activity by Lotfalipour and Ashna (2010). The results indicate that the most important factor in increasing CO_2 emissions is economic growth (scale effect), and economic structure is less effective in increasing carbon emissions. Fotros and Barati (2011) also used the IDA index decomposition analysis and showed that economic growth had the greatest positive effect on changes in CO_2 emissions in all economic sectors except industry and transportation and in the economy as a whole. Faridzad (2015) analyzed energy intensity in energy-intensive industries and stated that the effect of energy intensity has the greatest effect on increasing carbon emissions. Due to the wide range of consequences of air pollution on local to planetary scales, identifying the factors affecting pollution and emissions of polluting gases, including carbon dioxide, and determining the contribution of each of them can be a guide for environmental management in any country. Therefore, this study seeks to investigate and analyze the contribution and impact of factors affecting the spread of air pollution in Iran. The air pollution criterion is also considered to be the amount of CO_2 gas emissions - as one of the most important greenhouse gases - and an attempt is made to examine and analyze the contribution of factors such as population change, urbanization growth, and energy consumption to the amount of CO_2 emissions in the country during the period 1997 to 2016.

Europe's Insistence on Reducing Carbon Emissions

The European Commission is seeking to reduce Europe’s carbon emissions by 90% by 2040 and implement an industrial carbon management strategy to achieve this goal, despite strong opposition.
Growing opposition at the European level to tougher climate regulations and policies has not worked, and the European Commission has recommended in a statement that the EU should set an ambitious target of 90% reduction in greenhouse gas emissions by 2040 to put it on track for its Green Deal goal of net zero emissions by mid-century. The recommendation must be approved by the next European Commission before being scrutinized by the EU Council of Ministers and the European Parliament.
Given the potential for a right-wing swing in the June 2024 European Parliament elections, the debate on setting 2040 climate targets is seen as a key campaign issue this year by political parties that have openly opposed the costs of implementing such targets. In the latest response to the opposition, European Commission President Ursula von der Leyen appeared to bow to political pressure and withdrew her controversial plan to “Drastically reduce the use of chemical pesticides and greenhouse gas emissions from agriculture” after protests by farmers in France, Belgium and the Netherlands against the cost of clean energy regulations. The European Commission, meanwhile, published a proposed strategy for carbon management in the industrial sector, which emphasizes the role of “Direct carbon removal from the atmosphere” and “Carbon capture, utilization and storage” (CCUS) technologies. Carbon capture technologies should be deployed in sectors where emissions are hard to reduce and where alternative energy sources are not economically viable.
The plan stresses that removing carbon from the atmosphere is needed to achieve net-zero greenhouse gas emissions after 2050. The proposal sets out the enabling policy conditions necessary to achieve the 90% reduction target, with a particular focus on the role of carbon pricing. The European Commission said in a statement: “The Green Deal must now become an industrial decarburization agreement that builds on existing industrial strengths such as wind and hydropower, while continuing to increase domestic production capacity in growing sectors such as batteries, electric vehicles, heat pumps, solar photovoltaics (PV),

carbon capture, utilization and storage (CCUS), biogas, bio methane and the circular economy." The EU's Industrial Carbon Management Strategy stresses the need for rapid deployment of CCUS to achieve net-zero emissions. According to the document, around 280 million tons of CO_2 equivalent should be captured by 2040, increasing to 450 million tons of CO_2 equivalent by 2050. Storing 50 million tons of CO_2 equivalent emissions in 2030 is equivalent to Sweden's greenhouse gas emissions in 2022. Industry stakeholders have stated that if the necessary investment conditions are in place, up to 80 million tons of CO_2 could be captured annually in Europe by 2030. Northern Europe is investing significantly in CCUS and hydrogen infrastructure, but growth in this sector has been relatively slow, as many consider it expensive and its viability has not yet been proven on an industrial or commercial scale. In many cases, the cost of deploying CCUS technology far exceeds the cost of emissions. Although the number of contracts related to CCUS technology development is increasing, Platts data shows that between 2020 and 2023, contracts in this area were mainly for feasibility studies and advanced engineering and design (FEED) packages. In Europe, financing has been completed for only two truly large projects: The Northern Lights transport and storage project in Norway and the Porthos transport and storage center project in the Netherlands. The European Commission will set up a dedicated working group to develop a global approach to carbon pricing and carbon markets, and is also looking to develop policy options and support mechanisms for industrial carbon removals potentially included in the European Union Emissions Trading System (EU ETS). Carbon markets are seen as an effective and cost-effective way to reduce emissions under the EU standard, and governments are increasingly looking to use carbon pricing as part of their climate policies.

Several studies have examined the factors affecting environmental pollution and carbon dioxide emissions and their destructive consequences inside and outside the country, the most important of which are mentioned below. Arouri et al. (2012) in their study titled Energy Consumption, Economic Growth and CO_2 Production in the Middle East and North Africa countries, examined the relationship between CO_2 production and energy consumption and GDP in 12 countries in this region during the period 1981-2005. The results showed that in the long term there is a positive relationship between non-renewable energy consumption and CO_2 production. Jafari Samimi and Mohammadi Khyareh (2014) in their article studied the short-term and long-term relationship between carbon dioxide emissions, energy consumption and economic growth in the country during the period 1978-2010. The results of the Granger causality test show that there is a one-way causality relationship from GDP per capita to energy consumption per capita and carbon emissions per capita, while the causality relationship between employment rate and economic growth is one-way and from employment rate to economic growth. Tamizi (2015) examined the factors affecting carbon dioxide emissions in developing countries over a 23-year period from 1992 to 2014 using a Bayesian econometric approach. The results show that the Kuznets environmental hypothesis of an inverted U-shaped relationship between economic growth and environmental quality in developing countries is confirmed. The research findings also indicate that energy consumption variables, electricity consumption and industrialization variables have a positive relationship with carbon dioxide emissions. In contrast, the effect of literacy rate and income inequality on CO_2 emissions is decreasing. Çetin and Ecevit (2015) examined the cointegration and dynamic causal relationship between urbanization, energy consumption and carbon dioxide emissions in sub-Saharan Africa between 1985 and 2010. In this study, the Pedroni and Cao cointegration method and the Granger causality test based on the Vector Error Correction Model (VECM) were used for analysis. The results show that there is a cointegration relationship between the variables during this period and that energy consumption and urbanization are the main factors of environmental pollution in these countries. Xu and Lin (2016) examined the factors affecting CO_2 emissions in Chinese provinces during the period 1990-2014 using quantile regression. The results show that economic growth plays an important role in CO_2 emissions. The effect of energy intensity in provinces with a quantile less than 0.1 and more than 0.9 is stronger than that in provinces with a quantile between 0.5 and 0.25, which means that technological progress is more effective in reducing CO_2 emissions in provinces with a quantile less than 0.1 and more than 0.9 compared to provinces with a quantile between 0.5 and 0.25. Also, the effect of urbanization, industrialization and energy structure on CO_2 emissions is positive and significant. Behera and Dash (2017) in their paper examined the relationship between urbanization, energy consumption and foreign direct investment (FDI) and carbon dioxide emissions using panel data for 17 countries including low, middle and high income countries in the South and Southeast Asia (SSEA) region during the period 1980-2012. The results of this study show that primary energy consumption, fossil fuel energy consumption and foreign direct investment have a significant effect on CO_2 emissions in the SSEA region. Furthermore, empirical findings show that in middle-income countries, both primary and fossil fuel energy consumption significantly increase CO_2 emissions, creating a greenhouse gas emission problem in the SSEA region.

Conclusion

Pilot policies are often presented as innovative measures to reduce greenhouse gas emissions in low-carbon cities. Since 2010, these policies have been implemented, and so far their positive effects have not been clearly identified. This study uses urban panel data from 2007 to 2019 as a quasi-natural experiment to evaluate the impact of low-carbon pilot policies on carbon emissions. The results show that these policies can significantly reduce carbon emissions and use robustness tests to ensure the validity of the results. According to previous studies, it is clear that these policies mainly lead to carbon emission reductions by improving energy efficiency, industrial development, and technological productivity. This paper can play an explanatory role in the concept of low-carbon pilot policies and serve as a detailed guide to understanding the effects of these policies on carbon emissions. The keywords of this study include “Low-carbon pilot”, “Carbon emissions”, and “Significant differences”. In this context, the present paper presents new ideas and important suggestions for the formulation and implementation of low-carbon policies. Examining the strengths and weaknesses of these policies through urban panel data and validating the results using robustness testing makes this paper a reliable source for future studies in the field of greenhouse gas emission reduction. Therefore, this research is introduced as a useful guide for organizations, governments, and researchers engaged in environmental studies, urban planners, and policymakers active in the field of environment.

Today, the issue of information and communication technology and its role in reducing environmental pollution is an important topic in environmental economics, because information and communication technology helps to increase environmental pollution through the production of information and communication technology machines and devices, energy consumption and recycling of electronic waste. While information and communication technology is expected to reduce the emission of pollutants through the development of smart cities, transportation systems, electrical networks, industrial processes and energy saving. Therefore, the aim of this study is to investigate the effect of information and communication technology and economic growth on carbon dioxide emissions in the Persian Gulf countries during the period 2000-2015 using the panel data method. The results showed that information and communication technology has a direct effect and its square root has a negative and significant effect on carbon dioxide emissions. The result indicated the existence of an inverted U-shaped relationship between information and communication technology and carbon dioxide emissions. Economic growth has a direct effect and its square root has a negative effect on carbon dioxide emissions, which indicates the confirmation of the Kuznets hypothesis. Also, per capita energy consumption and trade have a direct and significant effect on carbon dioxide emissions. Therefore, by developing information and communication technology, the Gulf countries can help reduce their carbon dioxide emissions and environmental pollution.

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Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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