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Article

CO₂ Emissions in G20 Nations through the Three-Sector Model

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Abstract: This paper examines the relationship between CO₂ emissions in three economic sectors of G20 member countries using the environmental IPAT model and STIRPAT model and validates the EKC hypothesis by comparing the results for developing and developed countries. The results confirm that there is a significant long-run equilibrium relationship between the three sectors (primary, secondary, and tertiary) and CO₂ emissions across the panel. Furthermore, the long-run elasticities suggest that the primary sector (agriculture) positively and negatively affects the CO₂ emissions of developing and developed economies, respectively. This finding proves that the development of agriculture is in line with the EKC hypothesis that a more developed economy will instead improve environmental degradation. Based on the findings, for each sector, we provide policymakers with suggestions to potentially curb CO₂ emissions without significantly compromising economic growth.

Keywords: three-sector model; EKC; G20 nations; curbing CO₂ emissions; economic growth



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1. Introduction

Increasing concentrations of carbon dioxide (CO₂) emissions in the atmosphere have become a serious global concern, with CO₂ emissions being the main cause of many diseases and of temperature and sea level increases. Continued emissions will lead to further warming and long-term changes in the world's climate system, increasing the likelihood of severe, widespread and irreversible impacts on ecosystems (UN-Water 2020). Even though the reduction in CO₂ emissions is a global challenge, the standard of responsibility varies from country to country due to differences in energy efficiency, productivity, the stage of economic development, technological innovation and historical cumulative emissions. Therefore, although the importance of reducing CO₂ emissions is universally recognized, the international community has not reached a consensus on how much responsibility each country should assume to deal with these disasters, and this discrepancy is reflected mainly in the conflicts between developing and developed countries.

Some of the many international meetings that have been held to discuss the issue of emissions include the Kyoto Protocol in 1997, the Copenhagen Accord in 2009, and the Paris Agreement in 2015. The aim of these meetings has always been to set targets for reductions and to establish processes to achieve these targets. The most productive result of these meetings was that the parties to the Paris Agreement agreed to aim to control the increase in global average temperatures to between 1.5 and 2 °C (IPCC 2019) above preindustrial levels. However, lengthy negotiations between developing and developed countries (from 2015 to 2021 and not yet concluded) have prompted some scientists to revise the target for global average temperature rise, stating that it must now be limited to 1.5 °C above preindustrial levels or civilization will be seriously threatened (Lenton et al. 2019).

Making purely political compromises that disregard market realities may mean success for the Paris Agreement, but governments are only willing to actively cut carbon emissions if their economies do not suffer. The issue at stake is that CO₂ emissions are associated with economic activities, while a reduction in CO₂ emissions is associated with a sacrifice of economic growth. Therefore, reducing CO₂ emissions without sacrificing

economic development is the most acceptable solution for policymakers, as politicians cannot afford the political and developmental costs of significantly reducing carbon emissions at the domestic level. The environmental Kuznets curve (EKC) hypothesis provides the most desirable answer for humanity: “The solution to pollution is economic growth” (Roca et al. 2001).

The impact of economic growth on environmental degradation before and after the turning point of the inverted U-shaped curve implied by EKC is explained by academics in terms of scale, composition and technology, consistent with the three-sector model of economics. That is, in the preindustrial and industrial period, the labor force was concentrated in the primary sector (agriculture) and the secondary sector (manufacturing and industry), and economic growth was heavily dependent on the continuous expansion of production. This situation led to the consumption of large amounts of natural resources and rapid environmental degradation. The huge demand for natural resources has spurred sharp price increases and rising production costs. In this context, technology and productivity upgrades were used to improve energy efficiency and reduce energy consumption to stimulate economic growth. Environmental quality began to improve steadily, with increased levels of environmental awareness, regulation and education. As technology continues to advance and the economy becomes more reliant on services, the primary and secondary sectors will become more environmentally friendly (Panayotou 1993; Grossman 1995; Stern 2004).

A number of scholars have critically modeled the EKC hypothesis; the most recent review of the EKC hypothesis was conducted by Shahbaz and Sinha (2019) on 171 EKC studies of CO₂ emissions from 1991 to 2017. However, the findings of these studies suggest that the EKC results are doubtful with respect to the choice of control variables, pollution indicators, and environmental and methodological adaptation. Indeed, there are many other factors could influence the EKC results, such as government policy change, cumulative effect on emissions, and some special issues such as the 1980 oil crisis and global financial crisis. For this reason, the EKC hypothesis remains controversial in academic circles.

Significantly, scholars determine whether the EKC is effective by verifying the quadratic relationship¹ between economic and environmental variables (Dogan and Turkekul 2016; Yasin et al. 2020). Although the three effects of size, composition and technology in the context of the three-sector model play a very important role in the explanation of the EKC hypothesis and are generally accepted, the validity of the EKC hypothesis has rarely been tested by validating the relationship between the three-sector model and CO₂ emissions in developing and developed countries directly. That is, if economic growth reduces carbon emissions across all three sectors (primary, secondary and tertiary sectors), do developed and developing countries have the opposite result? The primary sector (agriculture), for example, produces more CO₂ emissions in developing countries but reduces CO₂ emissions in developed countries. In comparison to the many controversial validation formulas to determine whether EKC is valid, the three-sector model of validation can combine the three EKC effects with real industries to identify their patterns.

Moreover, few studies have employed the economic three-sector model in the area of CO₂ reduction. Previous studies in this area have focused on the relationship between specific variable(s) from one or two sectors and CO₂ emissions in one country or region (Shahbaz et al. 2013; Paramati et al. 2017; Dong et al. 2018). Motivated by these factors, this study aims to fill this research gap by identifying the factors that influence CO₂ reduction and economic development for different groups of economies within the context of the three-sector model. Furthermore, this is the first paper to test the EKC hypothesis by comparing the results of the impact of different sectors on CO₂ emissions in developed and developing countries. A better understanding of the relationship between these three economic sectors and CO₂ emissions can guide countries in reducing CO₂ emissions without significantly compromising economic growth and accelerate global cooperation in CO₂ reduction and investment (mutual wins with regard to the environment and the economy), further helping negotiations between developing and developed countries on the issue of emissions.

This paper selects variables that account for economic growth, CO₂ emissions, energy consumption, and technological advancement. Twelve variables² from the three sectors were chosen to test the elasticity between these variables and CO₂ emissions in G20 countries to explain the relationships among CO₂ emissions and the stage of development. The G20 countries are used as a data sample because their members cover a wide range of areas and are representative of the global economy. G20 members account for approximately 78% of GHG emissions (IPCC 2019) and 90% of the global economy, including 80% of the global trade volume (Burck et al. 2015). Thus, if the G20 members do not act, any impact on the emissions gap is likely to be very limited.

2. Literature Review

In the three-sector model, the development structure of a country's economy should evolve from the primary sector to the secondary sector and, finally, to the tertiary sector. The differences between each sector are reflected in workforce participation, technology, capital and development gaps (Bah 2007). These gaps affect how economic resources are reallocated in the economy and the distribution of pollution from country to country. The primary sector tends to make up a larger percentage of economies in developing economies than it does in developed economies. On average, developing economies distribute 6.5 times more of the workforce in agriculture than developed economies do (World Bank 2021). As the primary and secondary sectors become more technologically advanced in developed economies, productivity from resources results in greater yield per unit of resource input. Higher productivity and higher yield result in higher labor productivity and energy efficiency, resulting in more environmentally friendly production.

For developed economies, the productivity gap between sectors is small; economic growth results mainly from higher productivity and higher energy efficiency but not from the structural change from the primary sector to the secondary sector, for example, leading to the obsolescence of less productive firms caused by updating technology (Aghion and Howitt 1992; McMillan and Rodrik 2011; Roncolato and Kucera 2013; Morsy et al. 2015; Gai et al. 2021; Hamory et al. 2021).

Nevertheless, structural change, especially from the primary to the secondary sectors, has played a significant role in the economic growth of developing economies, particularly in the reallocation of labor from low-productivity sectors to higher-productivity sectors in modern service and manufacturing industries (Timmer and Akkus 2008). As agriculture formerly occupied a large share of the workforce, the possibility of labor reallocation through structural change provides opportunities. Structural change contributes to economic growth, a rise in labor productivity, an increase in the employment rate through quality jobs, a decrease in the poverty rate, an increase in per capita income and an increase in energy productivity (McMillan and Rodrik 2011; Morsy et al. 2015; Gai et al. 2021; Hamory et al. 2021).

Thus, the key areas of CO₂ emissions differ based on the essential differences in economic growth between developing and developed countries. The distribution of CO₂ emissions by industry sector for G20 countries in 2014³ (World Bank 2021) is exhibited in Table 1. This table indicates that the primary sector and secondary sectors of developing countries (2.64% and 67.41%) generated more CO₂ emissions than those in developed countries (1.68% and 56.70%). The tertiary sector contributed 41.61% of CO₂ emissions from developed countries, and this number for developing countries was approximately 30%. Thus, different distributions of sector CO₂ emissions indicate different directions in the environmental governance of CO₂ reduction for developing and developed countries in the G20.

Table 1. CO₂ emissions by industry sector for G20 countries in 2014.

G20 Countries	Primary Sector	Secondary Sector		Tertiary Sector	
	Other Sectors Including Agriculture (%)	Electricity and Heat Production (%)	Manufacturing Industries and Construction (%)	Transport (%)	Residential Buildings and Commercial and Public Services (%)
Developing countries in the G20					
Argentina	6.47%	38.04%	16.87%	24.17%	14.46%
Brazil	4.05%	26.31%	20.60%	44.75%	4.29%
China	2.07%	52.25%	31.72%	8.60%	5.36%
Indonesia	3.02%	53.61%	26.41%	11.48%	5.49%
India	1.43%	44.25%	18.40%	30.81%	5.11%
Mexico	2.07%	44.07%	13.45%	35.09%	5.32%
Russia	1.15%	61.11%	12.32%	16.24%	9.17%
Saudi Arabia	0.00%	49.16%	24.10%	25.92%	0.82%
Turkey	3.71%	46.69%	14.62%	19.83%	15.16%
South Africa	2.42%	67.48%	12.58%	12.05%	5.47%
Average	2.64%	48.30%	19.11%	22.89%	7.07%
Developed countries in the G20					
Australia	1.69%	58.36%	11.49%	24.74%	3.72%
Canada	2.91%	38.73%	12.04%	31.79%	14.52%
Germany	0.05%	48.47%	12.44%	21.37%	17.67%
France	4.70%	13.80%	15.70%	42.41%	23.40%
UK	0.96%	41.93%	9.60%	28.45%	19.06%
Italy	2.23%	35.56%	11.19%	32.95%	18.07%
Japan	0.21%	53.10%	19.18%	17.54%	9.98%
South Korea	1.45%	60.49%	13.66%	16.28%	8.13%
USA	0.94%	45.99%	8.66%	33.40%	11.01%
Average	1.68%	44.05%	12.66%	27.66%	13.95%

2.1. Primary Sector and CO₂ Emissions

In most of the developing countries, the highest proportion of the workforce and the generation of a large proportion of income are distributed throughout the production of agriculture, raw materials, livestock, fishing and forestry, which together make up the primary sector. Agriculture is an industry that uses the growth and development of plants and animals to obtain products through artificial cultivation; it is one of the basic industries that supports the construction and development of a national economy. For example, in Nigeria ([Odetola and Etumnu 2013](#); [Oluwole et al. 2021](#)), India ([Mahadevan 2003](#); [Orhan et al. 2021](#)), Indonesia ([Adebayo et al. 2021](#)), China ([Yao 2010](#); [Li et al. 2021](#)), Northern Cyprus ([Katircioglu 2006](#)), and developing countries ([Awokuse 2009](#); [Naseem and Tong 2021](#)), agriculture has contributed positively and consistently to economic growth.

The technology gap in agricultural practices among developed and developing countries has widened, especially in output per hectare and per worker. When the primary sector becomes more technologically advanced in developed countries, the productivity levels and yields for the same crop will be much higher than in developing countries ([Ruttan 2002](#); [Mohsin et al. 2021](#)). [Ball et al. \(2016\)](#) confirmed that the main contributor to economic growth in the US agriculture sector is productivity growth. Labor productivity can be improved by improvement in technologies and can create labor, providing workers for growing urban areas ([Huffman and Orazem 2007](#)). Furthermore, advanced technology will help maintain a rational energy structure in developed economies. Possible technologies that can create savings in energy of 10% to 40% include reduced soil tillage, optimized fertilizer efficiency, improved irrigation techniques and enhanced solar drying. Instead, fossil fuels with biomass will slow down CO₂ emissions; between 0.25 and 1 Gt of fossil fuel carbon could be replaced by agricultural biofuels per year ([Sauerbeck 2001](#)).

However, compared to CO₂ reduction, developing countries are more committed in poverty reduction and in the development of agriculture. In their analysis of multiyear data for 29 developing countries, [Webb and Block \(2012\)](#) indicated that when agriculture is supported by governments, poverty levels fall faster.

Consequently, agriculture may increase CO₂ emissions in developing countries and decrease CO₂ emissions in developed countries. Previous research has focused on the relationship between agriculture, the economy and technology for a specific country. As such, the relationship between the primary sector and CO₂ emissions has not been examined in a comprehensive manner.

2.2. Secondary Sector and CO₂ Emissions

The secondary sector contains middle per capita income countries that generate the main part of their income through industrial production and construction, such as mining, manufacturing, construction, and electricity, heat, energy, and water production and supply. The importance of the manufacturing industry for economies is self-evident; the higher the structure of a country's manufacturing sector is, the better it is able to develop a competitive service economy ([Guerrieri and Meliciani 2005](#); [Wu et al. 2021](#)). However, industry impacts CO₂ emissions heavily for both developing and developed countries ([Tunç et al. 2007](#); [Parikh et al. 2009](#); [Ali 2015](#); [Muangthai et al. 2016](#); [Yuan et al. 2017](#); [Abbasi et al. 2021a](#)). The difference is that developing economies have a more labor-intensive manufacturing goods industry structure than developed countries, while developed economies have a more technology-intensive industry structure ([Shafaeddin 2004](#); [Liu et al. 2021](#); [Shen et al. 2022](#)).

These differences impact countries' sensitivity to CO₂ emissions. For example, energy is an essential element of economic activity. At the same time, energy is the leading source of greenhouse gases. The global annual CO₂ concentration has increased by more than 48% since the start of industrialization in the mid-18th century, when humans' burning of biomass and fossil fuels to provide energy began on a significant scale ([Aziz et al. 2013](#); [Shafiei and Salim 2014](#); [Manuel et al. 2016](#); [Crafts and Mills 2017](#)). Furthermore, approximately 80% of energy sources and 66% of electricity sources in the world use nonrenewable energy from fossil fuels ([IPCC 2019](#)). Thus, after attempting to determine the positive relationship between energy consumption and economic growth, researchers suggested that countries enact more vigorous energy policies since reducing energy consumption will adversely affect GDP in the long run ([Ghosh 2002](#); [Lee and Chang 2008](#); [Zhang and Cheng 2009](#); [Abbasi et al. 2021b](#); [Khan et al. 2021](#)).

More importantly, inefficient energy production, less sophisticated energy production techniques and the large proportion of conventional energy in total energy consumption are the main weaknesses in developing economies. An example of this phenomenon occurs in China; [Guan et al. \(2009\)](#) indicated that by 2008, China was already the world's largest CO₂ emitter; however, a large proportion of these emissions could be reduced if China updated its inefficient coal-powered electricity system and coal for central heating in most of the northern regions during winter. [Yang et al. \(2018\)](#) stated that China's industrial sector uses mostly fossil fuel energy. When power generation switches to oil from thermal coal, CO₂ emissions decrease and GDP increases in both the short and long term ([Zhao et al. 2018](#)).

Intuitively, an increase in the proportion of renewable energy among all energy sources should decrease CO₂ emissions. Some scholars have also argued that there is a negative relationship between CO₂ emissions and renewable energy consumption ([Lee 2013](#); [Romano and Scandurra 2013](#); [Ben Jebli et al. 2014](#); [Shafiei and Salim 2014](#); [Agbelie 2016](#); [Asongu et al. 2016](#); [Manuel et al. 2016](#); [Riti and Shu 2016](#); [Spetan 2016](#); [Dudin et al. 2017](#); [Soylu et al. 2021](#); [Bekun 2022](#)). However, few researchers have indicated that there is a positive relationship between CO₂ emissions and renewable energy consumption. [Apergis et al. \(2010\)](#) examined the causal relationship between CO₂ emissions and renewable energy consumption for a group of 19 developed and developing countries for the period from 1984 to 2007 using a panel VECM model and found a statistically significant positive relationship between CO₂ emissions and renewable energy consumption in the long run. [Leitao \(2014\)](#) investigated

the correlation between CO₂ emissions and renewable energy for the period from 1970 to 2010 using time series data on the Portuguese economy and found that CO₂ emissions and renewable energy are positively correlated.

The relationship between CO₂ emissions and renewable energy consumption should be considered separately for developing economies and developed economies. Table 2 below shows that solid biofuels for traditional uses are the main renewable sources of energy for developing countries such as China (85.11%), Indonesia (82.24%), India (75.85), Saudi Arabia (100%) and South Africa (81.13%). Solid biofuels can be any biological material used as fuel, such as wood, sawdust, leaves, and dried animal dung (World Bank 2021). Thus, the solid biofuels for traditional uses will produce CO₂ emissions. Consequently, it is possible that renewable energy has a positive effect on CO₂ emissions for developing countries. Conversely, no developed economies use traditional solid biofuels as a source of renewable energy.

Table 2. The percentage of different types of renewable energy for all G20 economies in 2012.

Country	Solid Biofuels for Traditional Uses	Solid Biofuels for Modern Uses	Hydro Energy	Liquid Biofuels	Wind Energy	Solar Energy	Geothermal Energy	Waste Energy	Biogas Energy	Marine Energy
ARG	7.59%	37.75%	47.82%	6.73%	0.11%	0.00%	0.00%	0.00%	0.00%	0.00%
BRA	11.40%	41.23%	35.28%	11.70%	0.09%	0.27%	0.00%	0.00%	0.03%	0.00%
CHN	85.11%	0.36%	10.07%	0.48%	0.36%	1.23%	0.97%	0.00%	1.44%	0.00%
IDN	82.24%	15.28%	1.43%	0.31%	0.00%	0.00%	0.74%	0.00%	0.00%	0.00%
IND	75.85%	20.12%	3.59%	0.07%	0.26%	0.07%	0.00%	0.01%	0.03%	0.00%
MEX	0.00%	76.75%	18.37%	0.00%	0.23%	0.67%	3.96%	0.00%	0.02%	0.00%
RUS	16.69%	15.06%	68.16%	0.00%	0.00%	0.00%	0.10%	0.00%	0.00%	0.00%
SAU	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TUR	0.00%	61.69%	26.00%	0.22%	0.80%	3.06%	8.07%	0.00%	0.15%	0.00%
ZAF	81.13%	17.39%	1.03%	0.00%	0.05%	0.40%	0.00%	0.00%	0.00%	0.00%
Average	46.00%	28.56%	21.18%	1.95%	0.19%	0.57%	1.38%	0.00%	0.17%	0.00%
AUS	0.00%	69.56%	21.43%	3.13%	2.29%	2.43%	0.00%	0.00%	1.17%	0.00%
CAN	0.00%	26.94%	70.78%	1.53%	0.50%	0.01%	0.00%	0.11%	0.13%	0.01%
DEU	0.00%	47.18%	12.47%	12.13%	11.76%	3.99%	0.45%	5.42%	6.60%	0.00%
FRA	0.00%	61.36%	26.35%	5.73%	1.32%	0.32%	0.77%	3.23%	0.72%	0.21%
GBR	0.00%	30.71%	15.56%	22.41%	11.93%	1.76%	0.00%	4.98%	12.66%	0.00%
ITA	0.00%	24.40%	48.16%	11.64%	3.04%	2.14%	7.99%	1.18%	1.44%	0.00%
JPN	0.00%	29.86%	56.54%	0.00%	1.00%	7.39%	3.59%	1.62%	0.00%	0.00%
KOR	0.00%	26.70%	29.61%	12.86%	1.94%	4.37%	1.94%	16.02%	6.55%	0.00%
USA	0.00%	49.68%	27.60%	12.90%	2.82%	1.28%	2.25%	1.19%	2.28%	0.00%
Average	0.00%	40.71%	34.28%	9.15%	4.07%	2.63%	1.89%	3.75%	3.51%	0.02%

The replacement of nonrenewable energy with clean renewable energy is a possible solution for policymakers in developing policies for the management of CO₂ emissions without compromising economic growth (Ben Jebli et al. 2014; Riti and Shu 2016). Hydroelectricity is the main clean renewable energy source for Argentina (47.82%), Russia (68.16%), Canada (70.78%), Italy (48.16%) and Japan (56.54%). As a form of clean energy, hydroelectricity is highly used in both developing and developed economies. However, other clean energy resources, such as wind, solar, biogas and marine resources, are rarely used in developing economies. For example, almost zero percent of developing economies use marine energy. It is clear that high technology and huge amounts of capital are needed to develop, run and maintain these types of clean energy. Developing economies focus on infrastructure construction and attempt to increase their GDP, paying little attention to CO₂ emissions. In comparison, developed economies more consistently use all clean energy resources available. Wind energy accounts for 11.76% and 11.93% of the total renewable energy used in Germany and the United Kingdom, respectively. In Japan, solar energy accounts for 7.39% of the country’s total renewable energy usage. Biogas accounts for 12.66% of Germany’s renewable energy. Thus, policymakers need to consider CO₂ emissions from a global perspective, share their experiences in clean energy use with all countries, and cooperate with each other to break down the technical barriers to clean energy. The innovation and application of technology require significant capital investment; thus, a global green finance platform could also be considered for rapid establishment.

2.3. Tertiary Sector and CO₂ Emissions

Data for the tertiary sector show that highly developed economies attain a large percentage of their total economic outputs through services, education, tourism and transport. Sectors such as exports, imports, FDI inflows, FDI outflows, commercial services exports, commercial services imports, stock market capitalization and stock market trading value have been chosen as representative of the tertiary sector. Consider variables, exports, imports, commercial services exports and commercial services imports as examples. All of these variables differ in terms of their impact on CO₂ emissions in developing and developed countries.

(1) Exports and imports

Exports and imports are a very important component of a country's economy. Much of the previous literature shows that both exports and imports benefit economic growth at the country level (Fosu 1990; Ekanayake 1999; Awokuse 2007, 2008; Ugur 2008; Achchuthan 2013). Exports and imports enhance economic growth, and economic growth leads to energy demand and an increase in CO₂ emissions (Sánchez-Chóliz and Duarte 2004). After an investigation of 30 countries in the European Union between 1991 and 2012, Pie et al. (2018) found that the more a country imports, the higher the country's CO₂ emissions will be.

Some scholars have argued that the effect of exports and imports on CO₂ emissions is very different between developed and developing economies. Kondo et al. (1998) concluded that in Japan, the amount of CO₂ emissions embodied in imports was higher than that embodied in exports. Yan and Yang (2010) mentioned that imports produced 4.4% to 9.05% of China's annual CO₂ emissions, while exports produced 10.03% to 26.54% of its annual CO₂ emissions from 1997 to 2007. Davis and Caldeira (2010) found that imports to China and the United States were shown to contain 0.49 kg and 0.77 kg of CO₂ per dollar on average, respectively. They also found that in some Western countries, such as Switzerland, Sweden, Austria, the United Kingdom, and France, more than 30% of CO₂ emissions came from imports.

It seems that imports produce more CO₂ emissions in developed economies and that exports produce more CO₂ emissions in developing economies, which can be interpreted to mean that developing economies and developed economies are at different stages of development. The early stages of manufacturing will produce more CO₂ emissions than product innovation will. This finding can also be interpreted to mean that developing economies import CO₂ to developed countries and developed economies export CO₂ to developing countries (Yan and Yang 2010). Some scholars further suggested that developed economies should reduce their domestic emissions by increasing imports from developing economies (Weber and Matthews 2007; Wiedmann et al. 2008; Guan et al. 2009; Baiocchi and Minx 2010). These emissions may be transferred to other countries, such as China, as imports. Li and Hewitt (2008) indicated that 4% of China's CO₂ emissions are caused by consumption from the UK. Shui and Harriss (2006) found that approximately 7% to 14% of China's CO₂ emissions are due to consumption from the US. Thus, imports may reduce the domestic pollution level in developed economies.

(2) Commercial services

Typically, commercial services⁴ in the tertiary industry include high-tech products and services, such as information technology (IT), communication and telecommunication services. These advanced products and services generate high productivity for various economic sectors (Guerrieri and Meliciani 2005). As early as 1965, Fuchs (1965) discussed the concept of the "services economy", and since the mid-1950s, a low proportion of the U.S. workforce has been in the tangible goods sector. Information and communication technologies have become the basis of economic development strategies in recent years (Gibbs and Tanner 2010). Moreover, information and communication technologies have a significant impact on the trade performance of the manufacturing industry (Guerrieri and Meliciani 2005). Consequently, the growth of an economy is increasingly dependent on the

transmission of complex, unmodifiable information and communication services (Leamer and Storper 2001).

There are three reasons why the relationship between commercial services and CO₂ emissions differs between developing and developed countries. First, many of these services and products rely on high-tech equipment. Equipment design in developed countries and manufacturing in developing countries are part of a mature supply chain in the modern world. As shown by Yan and Yang (2010), developed countries import finished goods and services; therefore, they export CO₂ to developing countries. Second, electricity is the basic driving energy for many commercial services, but the energy structure is very different in developing and developed countries. The largest source of renewable energy in developing countries within the G20 is traditional, non-clean, solid biofuels, and in developed countries, these fuels are hardly used at all. Wee and Choi (2010) indicated that CO₂ emissions would be reduced by 87% and 97%, respectively, if solar cell and wind turbine systems, as renewable energy sources, were substituted for traditional electricity sources. Finally, innovation in commercial services happens very quickly. When a developed country invents a new product and updates many generations of that product, the developing country is completely left behind in terms of copyrights and options. More importantly, it is very difficult to offset the technology gap using either effort or capital (Guerrieri and Meliciani 2005). As such, importing and a backward energy structure will create a vicious cycle of CO₂ emissions in developing countries.

Table 3 below shows the volume of exports, imports, and exports minus imports of commercial services for the G20 economies in 2018⁵. Commercial services exports from developed economies are nine times greater than those from developing economies. Similarly, developed economies import five times more commercial services than developing economies. Developed economies show a USD 740.22 billion surplus of commercial services, while developing economies show a USD 390.03 billion deficit. In 2018, the technology gap between developing and developed economies was more than USD 1000 billion. Table 4⁶ below shows the preliminary analysis for the growth rate of commercial service exports for G20 countries from 1997 to 2018. The results indicate that the mean values for all countries are positive, which means that in recent years, commercial service exports have been increasing for all G20 countries. The BRICS countries show the highest mean growth rate among the G20 members: Brazil (11.05%), Russia (8.28%), India (17.7%), China (17.14%), and South Africa (6.72%). Moreover, developed economies show a smoother growth rate, while developing economies show more volatile values. The highest difference between the maximum and minimum values can be up to 223.2% for China. This is shown by skewness and kurtosis: most of the developed economies (90%) show a left skew (skewness is lower than 0), but developing economies show a half left skew and half right skew (skewness is greater than 0). Similarly, the kurtoses for developed economies are close to normal values (kurtosis is 3), but half of the developing economies show leptokurtosis, where kurtosis is greater than 3. This result is also supported by the Jarque–Bera (JB) test results, for which the null hypothesis for the JB test is normally distributed. Since all developed economies have not rejected the null hypothesis above a probability of 0.1%, the result suggests that commercial service export growth rates for all developed economies are normally distributed. In contrast, half of the developing economies rejected the null hypothesis of the JB test under a probability of 0.1%, and the results suggest that these countries are not normally distributed. Results with leptokurtic distributions are conventionally considered to be inherently more flexible than results with normal distributions (Stacey 2008). This evidence shows that commercial services in developing countries may have different reactions to CO₂ emissions than those in developed countries. To our knowledge, this is the first study to provide a comprehensive analysis of exports and imports of CO₂ emissions by commercial services in G20 nations.

Table 3. The volume of exports, imports, and exports minus imports of commercial services for the G20 nations in 2018.

	Country	Commercial Services Exports		Commercial Services Imports		Exports—Imports
		Billion USD	% G20 Total	Billion USD	% G20 Total	Billion USD
Developing Economies	ARG	13.91	0.26%	23.61	0.47%	−9.70
	BRA	33.22	0.62%	65.73	7.56%	−32.50
	CHN	231.81	4.33%	521.34	10.43%	−289.53
	IDN	27.21	0.51%	34.98	0.70%	−7.77
	MEX	28.81	0.54%	37.51	0.75%	−8.70
	RUS	63.74	1.19%	93.39	1.87%	−29.65
	SAU	17.39	0.32%	55.48	1.11%	−38.09
	TUR	48.19	0.90%	21.77	0.44%	26.43
	ZAF	15.59	0.29%	16.11	0.32%	−0.52
	Total	479.88	8.97%	869.90	17.40%	−390.03
Developed Economies	AUS	68.64	1.28%	71.61	1.43%	−2.98
	CAN	91.76	1.72%	111.83	2.24%	−20.07
	DEU	337.15	6.30%	363.88	7.28%	−26.73
	EUU	2490.17	46.55%	2109.82	42.20%	380.35
	FRA	291.92	5.46%	257.36	5.15%	34.56
	GBR	374.54	7.00%	229.01	4.58%	145.53
	ITA	120.73	2.26%	123.84	2.48%	−3.11
	JPN	188.94	3.53%	198.91	3.98%	−9.96
	KOR	97.96	1.83%	127.30	2.55%	−29.34
	USA	808.22	15.11%	536.24	10.73%	271.98
	Total	4870.02	91.03%	4129.80	82.60%	740.23

Table 4. Summary statistics of the commercial service export growth rate for the G20 countries from 1996 to 2018.

	Country	Mean	Median	Maximum	Minimum	S.D.	Skewness	Kurtosis	Jarque–Bera	Probability
Developing Economies	ARG	6.89%	4.51%	28.38%	−24.33%	0.1366	−0.1436	2.5455	0.2529	0.8812
	BRA	11.05%	11.05%	33.20%	−15.69%	0.1546	−0.2009	1.8155	1.3688	0.5044
	CHN	17.14%	5.98%	179.50%	−43.70%	0.4329	2.6201	10.7609	76.7306	0.0000
	IDN	10.75%	5.11%	141.85%	−36.10%	0.3557	2.3479	10.0299	62.5358	0.0000
	IND	17.70%	18.32%	59.73%	−12.48%	0.1569	0.5588	3.8596	1.7394	0.4191
	MEX	3.49%	3.52%	17.68%	−41.18%	0.1323	−1.9105	7.3224	29.1221	0.0000
	RUS	8.28%	10.56%	29.77%	−21.61%	0.1543	−0.5051	2.1363	1.5458	0.4617
	SAU	11.69%	7.39%	90.89%	−43.46%	0.2503	1.2620	6.9632	19.3181	0.0001
	TUR	7.66%	10.71%	49.03%	−30.17%	0.1913	−0.1011	2.7183	0.1052	0.9488
ZAF	6.72%	1.49%	70.00%	−10.87%	0.1707	2.5106	10.1130	66.3318	0.0000	
Developed Economies	AUS	6.40%	8.05%	22.40%	−10.85%	0.0934	−0.2298	2.4443	0.4551	0.7965
	CAN	5.84%	7.22%	17.66%	−8.75%	0.0694	−0.6688	2.8953	1.5750	0.4550
	DEU	7.75%	8.17%	27.61%	−7.46%	0.0915	0.2163	2.5845	0.3148	0.8544
	EUU	6.97%	7.76%	21.65%	−12.74%	0.0831	−0.2949	3.1482	0.3235	0.8506
	FRA	5.84%	7.32%	18.99%	−13.58%	0.0910	−0.5149	2.4961	1.1500	0.5627
	GBR	7.22%	7.52%	23.36%	−13.19%	0.0909	−0.1854	2.7048	0.1965	0.9064
	ITA	3.33%	2.64%	17.88%	−16.31%	0.0879	−0.3976	3.1614	0.5761	0.7497
	JPN	5.33%	4.72%	24.93%	−14.58%	0.0995	−0.0006	2.5103	0.2099	0.9004
	KOR	7.15%	9.07%	28.72%	−20.49%	0.1295	−0.2203	2.4987	0.3897	0.8229
USA	6.39%	6.88%	17.60%	−5.37%	0.0578	−0.1411	2.8256	0.0964	0.9530	

In conclusion, the composition effect of the EKC hypothesis requires pollution increases as the economic structure shifts from the primary sector to the secondary sector, and pollution decreases as the economic structure shifts towards the tertiary sector (Fan et al. 2019). Different countries are at different stages of development, and they rely differently on economic output, which means the same sector may have a different reaction to CO₂ emissions control among different economies. There are possibilities for international complementarity and cooperation in experience and technology for controlling CO₂

emissions. Motivated by the three-sector model in economics, this thesis examines the effect of primary, secondary, and tertiary sectors on CO₂ emissions across the panels of developing and developed economies of the G20 countries. There have been some studies that employed the economic three-sector model in the area of CO₂ emissions reduction. This study extends the existing literature by investigating the relationship between commercial service exports, commercial service imports, FDI outflows, and stock trade total value with CO₂ emissions.

3. Data and Methodology

3.1. Nature of the Data and Measurements

This study uses G20 countries as a data sample to systematically test the relationship between economic growth and CO₂ emissions through 12 selected variables for different developmental stages. G20 countries include developed and developing countries in different stages of development, and therefore, the findings can be generalized. Annual data from 1990 to 2014 were obtained from the World Bank Development Indicators⁷ online database for G20 countries, including Argentina (AGE), Australia (AUS), Brazil (BAR), Canada (CAN), China (CHN), Germany (DEU), France (FRA), the United Kingdom (GBR), Indonesia (IDN), India (IND), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), Russia (RUS), Saudi Arabia (SAU), Turkey (TUR), the United States (USA), and South Africa (ZAF). Balanced panel data are matched by years and countries with 500 observations for all G20 countries.

The measurements of the variables are as follows: CO₂ emissions (CDE) are measured in per capita kilotons; total population (POP) is in millions; GDP per capita (GDP) is in current US dollars; nonrenewable energy consumption (NREC) is the sum of gas, oil and coal measured in thousands of terajoules; renewable energy consumption (REC) is the sum of hydro, solid biofuels, wind, solar, liquid biofuels, biogas, geothermal, marine and waste measured in thousands of terajoules; exports of goods and services (EXT) are measured as a portion of GDP in current US dollars; imports of goods and services (IMT) are measured as a portion of GDP in current US dollars; commercial service exports (COE) are total service exports minus exports of government services not included elsewhere as a portion of GDP in current US dollars; commercial service imports (COI) are total service imports minus imports of government services not included elsewhere as a portion of GDP in current US dollars; foreign direct investment net inflows (FDINI) are measured as a portion of GDP in current US dollars; and foreign direct investment net outflows (FDINO) are measured as a portion of GDP in current US dollars. Agriculture (AGR) includes forestry, hunting, and fishing, as well as the cultivation of crops and livestock production and is measured as a portion of GDP in current US dollars; industry (IND) includes value added in mining, manufacturing (also reported as a separate subgroup), construction, electricity, water, and gas as a portion of GDP in current US dollars. Stock market capitalization (SMC) is the share price times the number of shares outstanding (including their several classes) for listed domestic companies as a portion of GDP in current US dollars; Stock trade total value (STV) is the total number of shares traded, both domestic and foreign, multiplied by their respective matching prices as a portion of GDP in current US dollars.

It is implied that the variables of this study were measured in different units to avoid the problem associated with distributional properties of the data series and generating elasticities in the regression models; therefore, it was necessary to transform all the variables into natural logarithms (Paramati et al. 2017). Thus, we transformed all the variables into natural logarithms before commencing the empirical analysis⁸.

3.2. Model Specification

The purpose of this study was to provide policymakers with potential suggestions for reducing CO₂ emissions without significantly compromising economic growth. This paper investigates the relationship between CO₂ emissions and 12 variables through the three-sector model of economies. To achieve these objectives, the existing environmental

IPAT model (Ehrlich and Holdren 1971; Raskin 1995; York et al. 2003; Paramati et al. 2016, 2017; Ozcan and Ulucak 2021) has been explored to determine the relationship between CO₂ emissions and 12 variables for the G20 countries. This model discusses the influences of population, GDP and technology factors on CO₂ emissions.

$$I = P \times A \times T \quad (1)$$

where I is the environmental impact sourced from the total population (P) of the underlying nation, (A) is the economic influence or per capita consumption, and (T) is the level of technology efficiency per capita or per dollar of GDP. This model has been further extended by Paramati et al. (2017) with a stochastic impacts by regression on population, affluence and technology (STIRPAT) model to identify the relationship between renewable energy, stock markets and CO₂ emissions. Thus, the following equation for our empirical studies has been built:

$$CDE_{it} = f(GDP_{it}, POP_{it}, Variable_{it}, \varepsilon_{it}) \quad (2)$$

where CO₂ emissions (CDE) are the environmental impact sourced from the economic influence of GDP, total population (POP) and economic variables from the three-sector model and 12 variables ($Variable_{it}$) through the three-sector model of economies⁹. Omitted-variable bias is another issue for EKC hypothesis analysis (Dogan and Turkekul 2016), and there have been a wide array of control variables disaggregated from total GDP into sectors used in the estimation of EKC. However, none of the studies of any of the sectors has produced a valid, unified EKC result. It is worth noting that there is no consensus in the academic community on the use of combinations of explanatory variables, which may lead to different results for different combinations of the same industry in the same country. For example, Abdallah et al. (2013) refuted the EKC hypothesis for Tunisia by examining the relationship between transport values added, road transport related energy consumption, road infrastructure, fuel price and CO₂ emissions from the Tunisian transport sector during the period 1980–2010. However, Talbi (2017) confirmed the EKC hypothesis for Tunisia by investigating the impact of energy consumption of fuel, energy intensity of road transport, economic growth, urbanization and fuel rate on CO₂ emissions in Tunisia. This indicates that stacking too many variables can make the results extremely unstable. Thus, our model aims at addressing the impact of a single variable from the three-sector model on CO₂ emissions by not accounting for any potential control variables. ε_{it} represents individual country effects. Countries and time periods are indicated by the subscripts i ($i = 1 \dots \dots , N$) and t ($t = 1 \dots \dots , N$), respectively.

4. Empirical Results and Discussion

4.1. Panel Unit Root Test

A unit root test was undertaken to measure whether the sample variable is stationary. To examine the distributional properties and order of integration of the variables, two generations of tests have been developed: a first-generation Im et al. (2003) panel unit root test (IPS) assumes cross-sectional independence across all units; a second-generation Pesaran (2003) cross-section augmented Dickey–Fuller (CADF) panel unit root test assumes heterogeneous panels with cross-sectional dependence across all units (Barbieri 2006). The null hypothesis of a unit root is nonstationary, as opposed to the alternative hypothesis of a stationary series with no unit root (Barbieri 2006). The results of the IPS and Pesaran's CADF unit root tests confirm that all of the variables are nonstationary at level $I(0)$ and stationary at their first-order differences $I(1)$. This finding implies that all of the variables have the same order of integration and may have a long-run cointegration relationship among all the variables. Moreover, nonstationarity at level $I(0)$ and stationarity of first-order differences $I(1)$ is the requirement of the Fisher-Johansen cointegration test and fully modified ordinary least squares (FMOLS). Thus, the cointegration test for the applied models will be introduced in the next section.

4.2. Cointegration (Long-Run Relationship)

The results of the panel unit root test in Table 5 confirm that all of the variables have the same order of integration and that there may be a long-run cointegration relationship among all of the variables. Thus, the Fisher-type Johansen panel cointegration test has been introduced to explore the long-run equilibrium relationship among the variables in Equation (2). The results of this test are reported in Table 6. The results show that there is a significant long-run relationship among the variables in each equation for all G20 countries and for the subsamples of developing and developed G20 economies.

Table 5. Panel unit root tests (full sample).

At Level	IPS Panel Unit Root Test Assumes Cross-Sectional Independence		Pesaran’s CADF Unit Root Test Assumes Cross-Sectional Dependence	
	Statistic	p-Value	Z [t-Bar]	p-Value
CDE	2.574	0.995	3.925	1.000
GDP	−0.882	0.189	1.500	0.933
POP	6.556	1.000	1.293	0.902
EXT	−0.266	0.395	0.935	0.825
IMT	−0.314	0.377	0.903	0.817
REC	0.673	0.749	0.298	0.617
NREC	2.909	0.998	3.600	1.000
AGR	−0.089	0.465	1.592	0.944
IND	−0.367	0.357	0.912	0.819
SMC	−0.605	0.273	3.257	0.999
STV	0.001	0.500	1.287	0.901
COE	−0.902	0.184	1.444	0.926
COI	−1.184	0.118	−0.539	0.295
FDINI	−0.937	0.175	0.735	0.769
FDINO	−1.043	0.149	1.035	0.850
At first difference				
CDE	−7.018 ***	0.000	−2.935 ***	0.002
GDP	−6.356 ***	0.000	−3.029 ***	0.001
POP	−4.373 ***	0.000	−3.438 ***	0.000
EXT	−7.370 ***	0.000	−3.736 ***	0.000
IMT	−8.433 ***	0.000	−4.581 ***	0.000
REC	−8.517 ***	0.000	−5.355 ***	0.000
NREC	−7.682 ***	0.000	−3.251 ***	0.001
AGR	−8.129 ***	0.000	−6.789 ***	0.000
IND	−8.625 ***	0.000	−5.576 ***	0.000
SMC	−14.403 ***	0.000	−3.044 ***	0.001
STV	−6.665 ***	0.000	−2.720 ***	0.003
COE	−7.008 ***	0.000	−3.723 ***	0.000
COI	−6.237 ***	0.000	−3.980 ***	0.000
FDINI	−8.234 ***	0.000	−4.271 ***	0.000
FDINO	−10.264 ***	0.000	−6.800 ***	0.000

Note: (1) The symbols *** reveal that the t-test is significant at the thresholds of 1%, 5%, and 10%, respectively, which means that the null hypothesis is rejected; (2) the unit root tests are estimated using constant and trend variables; and (3) all tests are explored using Stata.

Table 6. Johansen Fisher panel cointegration test.

Hypothesized	G20				Developing				Developed			
	Fisher Stat. *	Fisher Stat. *		Fisher Stat. *	Fisher Stat. *	Fisher Stat. *		Fisher Stat. *	Fisher Stat. *	Fisher Stat. *		
No. of CE(s)	(from Trace Test)	Prob.	(from Max-Eigen Test)	Prob.	(from Trace Test)	Prob.	(from Max-Eigen Test)	Prob.	(from Trace Test)	Prob.	(from Max-Eigen Test)	Prob.
Model 1a : $CDE_{it} = f(GDP_{it}, POP_{it}, AGR, \epsilon_{it})$												
None	315.10 ***	0.0000	249.20 ***	0.0000	214.90 ***	0.0000	168.90 ***	0.0000	165.00 ***	0.0000	108.70 ***	0.0000
At most 1	128.70 ***	0.0000	83.38 ***	0.0001	87.23 ***	0.0000	56.98 ***	0.0000	87.46 ***	0.0000	60.76 ***	0.0000
At most 2	83.72 ***	0.0001	70.77 ***	0.0019	52.03 ***	0.0001	47.70 ***	0.0005	44.80 ***	0.0012	32.74 **	0.0360
At most 3	55.98 **	0.0480	55.98 **	0.0480	26.49	0.1501	26.49	0.1501	46.03 ***	0.0008	46.03 ***	0.0008
Model 1b : $CDE_{it} = f(GDP_{it}, POP_{it}, IND, \epsilon_{it})$												
None	346.70 ***	0.0000	240.20 ***	0.0000	217.10 ***	0.0000	156.00 ***	0.0000	173.40 ***	0.0000	138.30 ***	0.0000
At most 1	168.70 ***	0.0000	111.60 ***	0.0000	101.80 ***	0.0000	67.27 ***	0.0000	74.44 ***	0.0000	48.23 ***	0.0004
At most 2	102.40 ***	0.0000	82.18 ***	0.0001	59.56 ***	0.0000	47.96 ***	0.0004	44.22 ***	0.0014	33.63 **	0.0288
At most 3	68.69 ***	0.0032	68.69 ***	0.0032	39.13 ***	0.0064	39.13 ***	0.0064	44.93 ***	0.0011	44.93 ***	0.0011
Model 2a : $CDE_{it} = f(GDP_{it}, POP_{it}, REC, \epsilon_{it})$												
None	355.80 ***	0.0000	272.90 ***	0.0000	244.90 ***	0.0000	180.70 ***	0.0000	110.90 ***	0.0000	67.12 ***	0.0000
At most 1	158.50 ***	0.0000	100.80 ***	0.0000	100.90 ***	0.0000	63.61 ***	0.0000	57.59 ***	0.0000	37.15 **	0.0050
At most 2	90.79 ***	0.0000	63.76 ***	0.0055	55.61 ***	0.0000	39.54 ***	0.0057	35.18 ***	0.0090	24.21	0.1481
At most 3	102.60 ***	0.0000	102.60 ***	0.0000	55.17 ***	0.0000	55.17 ***	0.0000	47.40 ***	0.0002	47.40 ***	0.0002
Model 2b : $CDE_{it} = f(GDP_{it}, POP_{it}, NREC, \epsilon_{it})$												
None	382.00 ***	0.0000	272.90 ***	0.0000	281.40 ***	0.0000	209.90 ***	0.0000	100.60 ***	0.0000	63.07 ***	0.0000
At most 1	163.40 ***	0.0000	95.52 ***	0.0000	112.20 ***	0.0000	64.72 ***	0.0000	51.18 ***	0.0000	30.81 **	0.0303
At most 2	104.20 ***	0.0000	70.72 ***	0.0010	68.48 ***	0.0000	49.85 ***	0.0002	35.74 ***	0.0076	20.87	0.2863
At most 3	106.10 ***	0.0000	106.10 ***	0.0000	57.86 ***	0.0000	57.86 ***	0.0000	48.25 ***	0.0001	48.25 ***	0.0001
Model 3a : $CDE_{it} = f(GDP_{it}, POP_{it}, FDINI, \epsilon_{it})$												
None	342.70 ***	0.0000	258.70 ***	0.0000	238.00 ***	0.0000	181.70 ***	0.0000	158.20 ***	0.0000	118.40 ***	0.0000
At most 1	157.00 ***	0.0000	102.00 ***	0.0000	106.80 ***	0.0000	69.19 ***	0.0000	61.79 ***	0.0000	39.98 ***	0.0050
At most 2	94.71 ***	0.0000	83.32 ***	0.0000	60.37 ***	0.0000	57.02 ***	0.0000	41.36 ***	0.0033	30.52 *	0.0619
At most 3	49.57 *	0.0990	49.57 *	0.0990	22.21	0.2229	22.21	0.2229	42.15 ***	0.0026	42.15 ***	0.0026
Model 3b : $CDE_{it} = f(GDP_{it}, POP_{it}, FDINO, \epsilon_{it})$												
None	343.7 ***	0.0000	259.9 ***	0.0000	258.4 ***	0.0000	202.3 ***	0.0000	85.36 ***	0.0000	57.61 ***	0.0000
At most 1	147.8 ***	0.0000	105.3 ***	0.0000	101.6 ***	0.0000	78.78 ***	0.0000	46.19 ***	0.0008	26.49	0.1502
At most 2	85.4 ***	0.0000	71.78 ***	0.0015	47.94 ***	0.0004	42.37 ***	0.0025	37.46 **	0.0103	29.42 *	0.0798
At most 3	57.16 **	0.0384	57.16 **	0.0384	27.53	0.1210	27.53	0.1210	29.63 *	0.0760	29.63 *	0.0760

Table 6. Cont.

Hypothesized	G20				Developing				Developed			
	No. of CE(s)	Fisher Stat. * (from Trace Test)	Prob.	Fisher Stat. * (from Max-Eigen Test)	Prob.	Fisher Stat. * (from Trace Test)	Prob.	Fisher Stat. * (from Max-Eigen Test)	Prob.	Fisher Stat. * (from Trace Test)	Prob.	Fisher Stat. * (from Max-Eigen Test)
Model 4a : $CDE_{it} = f(GDP_{it}, POP_{it}, SMC, \epsilon_{it})$												
None	191.70 ***	0.0000	129.50 ***	0.0000	103.40 ***	0.0000	77.16 ***	0.0000	88.37 ***	0.0000	52.33 ***	0.0000
At most 1	96.40 ***	0.0000	68.23 ***	0.0001	42.37 ***	0.0000	31.59 ***	0.0016	54.03 ***	0.0000	36.65 ***	0.0058
At most 2	57.46 ***	0.0018	44.08 **	0.0469	23.57 **	0.0232	18.04	0.1146	33.88 **	0.0130	26.05 *	0.0986
At most 3	48.27 **	0.0186	48.27 **	0.0186	21.42 **	0.0446	21.42 **	0.0446	26.86 *	0.0817	26.86 *	0.0817
Model 4b : $CDE_{it} = f(GDP_{it}, POP_{it}, STV, \epsilon_{it})$												
None	361.70 ***	0.0000	272.60 ***	0.0000	257.90 ***	0.0000	202.40 ***	0.0000	103.90 ***	0.0000	70.26 ***	0.0000
At most 1	167.90 ***	0.0000	123.30 ***	0.0000	112.90 ***	0.0000	91.58 ***	0.0000	54.95 ***	0.0000	31.74 **	0.0462
At most 2	88.01 ***	0.0000	66.72 ***	0.0027	46.06 ***	0.0003	33.47 ***	0.0146	41.94 ***	0.0028	33.25 **	0.0317
At most 3	69.31 ***	0.0014	69.31 ***	0.0014	37.76 ***	0.0042	37.76 ***	0.0042	31.55 **	0.0484	31.55 **	0.0484
Model 5a : $CDE_{it} = f(GDP_{it}, POP_{it}, EXT, \epsilon_{it})$												
None	293.60 ***	0.0000	216.20 ***	0.0000	186.50 ***	0.0000	141.70 ***	0.0000	107.10 ***	0.0000	74.51 ***	0.0000
At most 1	135.10 ***	0.0000	81.23 ***	0.0001	78.44 ***	0.0000	46.38 ***	0.0007	56.63 ***	0.0000	34.85 **	0.0209
At most 2	94.48 ***	0.0000	75.45 ***	0.0006	54.01 ***	0.0001	44.48 ***	0.0013	40.48 ***	0.0043	30.97 *	0.0555
At most 3	64.57 ***	0.0082	64.57 ***	0.0082	34.52 **	0.0228	34.52 **	0.0228	30.05 *	0.0690	30.05 *	0.0690
Model 5b : $CDE_{it} = f(GDP_{it}, POP_{it}, IMT, \epsilon_{it})$												
None	350.50 ***	0.0000	242.60 ***	0.0000	243.40 ***	0.0000	177.40 ***	0.0000	107.10 ***	0.0000	65.18 ***	0.0000
At most 1	173.90 ***	0.0000	110.60 ***	0.0000	111.70 ***	0.0000	71.02 ***	0.0000	62.23 ***	0.0000	39.62 ***	0.0056
At most 2	109.10 ***	0.0000	85.89 ***	0.0000	66.85 ***	0.0000	52.61 ***	0.0001	42.29 ***	0.0025	33.29 **	0.0314
At most 3	71.11 ***	0.0018	71.11 ***	0.0018	41.56 ***	0.0032	41.56 ***	0.0032	29.55 *	0.0775	29.55 *	0.0775
Model 6a : $CDE_{it} = f(GDP_{it}, POP_{it}, COE, \epsilon_{it})$												
None	296.90 ***	0.0000	226.10 ***	0.0000	186.60 ***	0.0000	153.80 ***	0.0000	110.20 ***	0.0000	72.26 ***	0.0000
At most 1	126.90 ***	0.0000	79.49 ***	0.0002	69.16 ***	0.0000	40.41 ***	0.0044	57.79 ***	0.0000	39.07 ***	0.0065
At most 2	87.39 ***	0.0000	76.91 ***	0.0004	49.63 ***	0.0003	43.88 ***	0.0016	37.76 ***	0.0095	33.03 **	0.0335
At most 3	53.69 *	0.0726	53.69 *	0.0726	28.95 *	0.0888	28.95 *	0.0888	24.74	0.2116	24.74	0.2116
Model 6b : $CDE_{it} = f(GDP_{it}, POP_{it}, COI, \epsilon_{it})$												
None	351.00 ***	0.0000	248.00 ***	0.0000	252.90 ***	0.0000	191.00 ***	0.0000	98.11 ***	0.0000	57.06 ***	0.0000
At most 1	179.70 ***	0.0000	122.20 ***	0.0000	121.10 ***	0.0000	89.30 ***	0.0000	58.61 ***	0.0000	32.94 **	0.0342
At most 2	103.20 ***	0.0000	86.93 ***	0.0000	57.51 ***	0.0000	46.71 ***	0.0006	45.72 ***	0.0009	40.23 ***	0.0047
At most 3	63.49 **	0.0105	63.49 **	0.0105	36.30 **	0.0142	36.30 **	0.0142	27.19	0.1300	27.19	0.1300

Note: The symbols ***, **, and * reveal that the *t*-test is significant at the thresholds of 1%, 5%, and 10%, respectively, which means that the null hypothesis is rejected.

4.3. The Long-Run CO₂ Emissions Output Elasticity (FMOLS) Results and Policy Implications

The cointegration test confirmed that there is a long-run equilibrium relationship among these variables. Furthermore, the FMOLS technique in Equations (2) has been explored to generate the long-run elasticities. The empirical results of these models are presented in Table 7.

Table 7. FMOLS long-run elasticities.

G20			Developing			Developed		
Variable	Coefficient	Prob.	Variable	Coefficient	Prob.	Variable	Coefficient	Prob.
Primary sector								
Model 1a : $CDE_{it} = f(GDP_{it}, POP_{it}, AGR, \epsilon_{it})$								
GDP	0.3111 ***	0.0000	GDP	0.2307 ***	0.0000	GDP	0.2147 ***	0.0000
POP	0.3838 ***	0.0000	POP	0.5032 ***	0.0000	POP	0.0149 ***	0.0019
AGR	0.1992 ***	0.0000	AGR	0.1943 ***	0.0000	AGR	−0.0469 ***	0.0001
R-squared	0.9782		R-squared	0.9818		R-squared	0.8882	
Adjusted R-squared	0.9771		Adjusted R-squared	0.9808		Adjusted R-squared	0.8817	
Secondary sector								
Model 1b : $CDE_{it} = f(GDP_{it}, POP_{it}, IND, \epsilon_{it})$								
GDP	0.2134 ***	0.0000	GDP	0.2754 ***	0.0000	GDP	0.3452 ***	0.0000
POP	0.2166 ***	0.0000	POP	0.2060	0.1731	POP	0.1429 ***	0.0000
IND	0.4900 ***	0.0000	IND	0.2395 *	0.0583	IND	0.7072 ***	0.0000
R-squared	0.9812		R-squared	0.9833		R-squared	0.8960	
Adjusted R-squared	0.9802		Adjusted R-squared	0.9824		Adjusted R-squared	0.8900	
Model 2a : $CDE_{it} = f(GDP_{it}, POP_{it}, REC, \epsilon_{it})$								
GDP	0.3605 ***	0.0000	GDP	0.2663 ***	0.0000	GDP	0.2877 ***	0.0000
POP	0.2342 ***	0.0000	POP	0.2451 ***	0.0000	POP	−0.3588 ***	0.0000
REC	−0.2530 ***	0.0000	REC	0.0430 ***	0.0000	REC	−0.1253 ***	0.0000
R-squared	0.9762		R-squared	0.9831		R-squared	0.9342	
Adjusted R-squared	0.9750		Adjusted R-squared	0.9822		Adjusted R-squared	0.9307	
Model 2b : $CDE_{it} = f(GDP_{it}, POP_{it}, NREC, \epsilon_{it})$								
GDP	0.0643 ***	0.0000	GDP	0.0731 ***	0.0000	GDP	0.1273 ***	0.0000
POP	−1.2809 ***	0.0000	POP	−1.1344 ***	0.0000	POP	−1.1071 ***	0.0000
NREC	0.9074 ***	0.0000	NREC	0.7970 ***	0.0000	NREC	1.1017 ***	0.0000
R-squared	0.9956		R-squared	0.9935		R-squared	0.9841	
Adjusted R-squared	0.9954		Adjusted R-squared	0.9932		Adjusted R-squared	0.9832	
Tertiary sector								
Model 3a : $CDE_{it} = f(GDP_{it}, POP_{it}, FDINI, \epsilon_{it})$								
GDP	0.2346 ***	0.0000	GDP	0.1752 ***	0.0000	GDP	0.1257 ***	0.0000
POP	0.2171 ***	0.0000	POP	0.4131 ***	0.0000	POP	−0.0477 ***	0.0000
FDINI	0.0269 ***	0.0000	FDINI	−0.0231 ***	0.0011	FDINI	0.0054	0.7919
R-squared	0.9760		R-squared	0.9783		R-squared	0.9283	
Adjusted R-squared	0.9747		Adjusted R-squared	0.9770		Adjusted R-squared	0.9243	

Table 7. Cont.

G20			Developing			Developed		
Variable	Coefficient	Prob.	Variable	Coefficient	Prob.	Variable	Coefficient	Prob.
Model 3b : $CDE_{it} = f(GDP_{it}, POP_{it}, FDINO, \epsilon_{it})$								
GDP	0.1990 ***	0.0000	GDP	0.1443 ***	0.0000	GDP	0.0755 ***	0.0000
POP	0.1487 ***	0.0000	POP	0.3314 ***	0.0000	POP	0.0316 ***	0.0000
FDINO	-0.0096	0.2954	FDINO	0.0041	0.7447	FDINO	-0.0950 ***	0.0005
R-squared	0.9763		R-squared	0.9748		R-squared	0.8956	
Adjusted R-squared	0.9750		Adjusted R-squared	0.9732		Adjusted R-squared	0.8898	
Model 4a : $CDE_{it} = f(GDP_{it}, POP_{it}, SMC, \epsilon_{it})$								
GDP	0.0306 **	0.0135	GDP	0.2560 ***	0.0000	GDP	0.1648 ***	0.0000
POP	-0.0489 ***	0.0000	POP	0.0030	0.0000	POP	-0.0386 ***	0.0000
SMC	0.0384 ***	0.0000	SMC	0.0005	0.0000	SMC	-0.0271 **	0.0711
R-squared	0.9810		R-squared	0.9883		R-squared	0.9420	
Adjusted R-squared	0.9798		Adjusted R-squared	0.9874		Adjusted R-squared	0.9385	
Model 4b : $CDE_{it} = f(GDP_{it}, POP_{it}, STV, \epsilon_{it})$								
GDP	0.2464 ***	0.0000	GDP	0.1427 ***	0.0000	GDP	0.1956 ***	0.0000
POP	0.0663 ***	0.0000	POP	0.1741 ***	0.0000	POP	-0.1025 ***	0.0000
STV	-0.0164	0.5718	STV	0.1089 ***	0.0000	STV	0.0232 ***	0.0008
R-squared	0.9822		R-squared	0.9689		R-squared	0.9338	
Adjusted R-squared	0.9812		Adjusted R-squared	0.9669		Adjusted R-squared	0.9300	
Model 5a : $CDE_{it} = f(GDP_{it}, POP_{it}, EXT, \epsilon_{it})$								
GDP	0.2358 ***	0.0000	GDP	0.2187 ***	0.0000	GDP	0.1174 ***	0.0000
POP	0.0740 ***	0.0000	POP	-0.0035 *	0.0504	POP	0.0409 ***	0.0000
EXT	0.0817 ***	0.0000	EXT	0.1973 ***	0.0000	EXT	-0.0059	0.7405
R-squared	0.9786		R-squared	0.983972		R-squared	0.9277	
Adjusted R-squared	0.9776		Adjusted R-squared	0.98311		Adjusted R-squared	0.9238	
Model 5b : $CDE_{it} = f(GDP_{it}, POP_{it}, IMT, \epsilon_{it})$								
GDP	0.2495 ***	0.0000	GDP	0.1551 ***	0.0000	GDP	0.1271 ***	0.0000
POP	0.1306 ***	0.0000	POP	0.1090 ***	0.0000	POP	0.0241 ***	0.0000
IMT	0.0337 ***	0.0000	IMT	0.2508 ***	0.0000	IMT	0.0487 ***	0.0000
R-squared	0.9781		R-squared	0.9813		R-squared	0.9222	
Adjusted R-squared	0.9770		Adjusted R-squared	0.9803		Adjusted R-squared	0.9179	
Model 6a : $CDE_{it} = f(GDP_{it}, POP_{it}, COE, \epsilon_{it})$								
GDP	0.2430 ***	0.0000	GDP	0.2583 ***	0.0000	GDP	0.1814 ***	0.0000
POP	0.2293 ***	0.0000	POP	0.1985 ***	0.0000	POP	-0.0110 **	0.0164
COE	-0.0457 ***	0.0000	COE	0.0636 ***	0.0000	COE	-0.0999 ***	0.0000
R-squared	0.9782		R-squared	0.9839		R-squared	0.9253	
Adjusted R-squared	0.9772		Adjusted R-squared	0.9830		Adjusted R-squared	0.9213	
Model 6b : $CDE_{it} = f(GDP_{it}, POP_{it}, COI, \epsilon_{it})$								
GDP	0.2213 ***	0.0000	GDP	0.2613 ***	0.0000	GDP	0.1349 ***	0.0000
POP	0.2056 ***	0.0000	POP	0.2002 ***	0.0000	POP	0.0237 ***	0.0000
COI	0.0617 ***	0.0000	COI	0.1808 ***	0.0000	COI	-0.0152 ****	0.0645
R-squared	0.9780		R-squared	0.9839		R-squared	0.9255	
Adjusted R-squared	0.9769		Adjusted R-squared	0.9831		Adjusted R-squared	0.9215	

Note: The symbols *** and ** reveal that the t-test is significant at the thresholds of 1%, 5%, and 10%, respectively.

The results in Models 1a and 1b imply that for every 1% increase in industry, CO₂ emissions will increase by 0.4900%, 0.2395% and 0.7072% for the full sample of G20 countries and for the subsamples of developing and developed economies, respectively. Here, the developed economies show a 3 times higher increase than the developing economies in the G20. On the other hand, for every 1% increase in agriculture, CO₂ emissions decrease by 0.0469% in developed economies, while they increase by 0.1943% in developing economies. This result implies that CO₂ emissions are more sensitive in the agricultural sector of developed countries than in that of developing economies. Moreover, the role of agriculture in CO₂ emissions is not consistent across developed and developing economies.

The output elasticities in Models 2a and 2b show that for every percentage point of energy use that falls into the category of nonrenewable energy, CO₂ emissions will increase by 0.9074%, 0.7979%, and 1.1017% for the full sample and the subsamples of developing and developed economies, respectively. A 1% rise in renewable energy consumption reduces CO₂ emissions by 0.2530% and 0.1253% in the full sample and among the subsample of developed economies, respectively, while it raises CO₂ emissions by 0.0430% for developing economies in the G20. The result implies that nonrenewable energy consumption is significantly positively related to CO₂ emissions across the panel. Moreover, renewable energy has a positive effect on CO₂ emissions in developing countries.

The results in Models 3a and 3b imply that a 1% increase in FDI inflows decreases the CO₂ emissions of developing economies by 0.0231%; on the other hand, a 1% increase in FDI outflows decreases the CO₂ emissions of developed economies by 0.095%. The results show that developing and developed economies experience different degrees of CO₂ reduction.

The output elasticities, as per Models 4a and 4b, show that for every 1% increase in the stock market capitalization of listed domestic companies (SMC), CO₂ emissions will decrease by 0.0271% in developed economies within the G20, while they will increase by 0.0005% in developing economies within the G20. Stock trading volume (STV) is positively related to CO₂ emissions in both developing and developed economies, increasing emissions by 0.1089% and 0.0232%, respectively. This finding implies that developing stronger capital markets will help reduce CO₂ emissions, whereas stock trading numbers have a significantly positive relationship with CO₂ emissions across the panel.

The results in Models 5a and 5b show that a 1% increase in exports raises CO₂ emissions by 0.0817% and 0.1973% in the full G20 sample and the subsample of developing economies, respectively. A 1% increases in imports increases CO₂ emissions in the full sample and subsamples of developing and developed economies by 0.0337%, 0.2508% and 0.0478%, respectively. The elasticity gap of imports with CO₂ emissions is very large between developing and developed economies, and in developing economies, it is 5 times more than that in developed economies. This result implies that exports will be accompanied by CO₂ emissions during processing in all G20 economies, especially in developing economies. Moreover, within the G20 countries, developed economies import more environmentally friendly products than developing economies.

The results in Models 6a and 6b imply that a 1% increase in commercial service exports (COE) will decrease CO₂ emissions by 0.1% and 0.047% in developed countries and in the full G20 sample, respectively, while increasing them by 0.0636% in developing economies. Similarly, a 1% increase in commercial service imports (COI) will increase CO₂ emissions by 0.1808% for developing economies and reduce them by 0.0152% for developed economies. This result implies that the role of both commercial service exports and commercial service imports on CO₂ emissions is consistent across the developed and developing economies of the G20.

4.3.1. Primary Sector and CO₂ Emissions

Agriculture in the primary sector in developed economies is working in favor of reducing CO₂ emissions; however, agriculture has a positive impact on CO₂ emissions in the case of developing economies. This simultaneously validates the EKC hypothesis, which can

be interpreted to mean that the modernization of farming practices will not only increase economic growth by improvements to inter-sector and intra-sector productivity but also optimize energy efficiency and increase energy productivity, causing a reduction in CO₂ emissions. Therefore, we suggest that policymakers in developing economies upgrade productive infrastructure, increase land consolidation and modernization, accumulate capital and increase investment in science, research and technology capacity in the primary sector, while developed countries need to extend their experience and advance their technology in productivity and technology efficiency globally.

Our findings also prove that the development of agriculture is in line with the EKC hypothesis that a more developed economy will improve environmental degradation. Technology, productivity and energy efficiency will be upgraded alongside rapid economic development, thus reducing energy consumption to stimulate economic growth and making the primary sector more environmentally friendly.

4.3.2. Secondary Sector and CO₂ Emissions

The impact of the secondary sector on CO₂ emissions can be divided into two groups. The first group consists of variables related to industry that are significantly positively related to CO₂ emissions for developing and developed economies in the G20, such as industry and nonrenewable consumption. Since developed economies show a 3 times greater increase in CO₂ emissions than developing economies in the G20 for every 1% increase in industry, we can confirm that the industry sector in developed countries is more sensitive to CO₂ emissions than that in developing countries. This finding implies that developed economies assemble and manufacture many products in developing economies, while they are responsible only for designing and supervising the production of these products. As a result, a small increase in industry would have a strong impact on CO₂ emissions. This finding can also be interpreted to mean that the secondary sector supports both the primary sector and the tertiary sector with light industry and heavy industry. Therefore, we suggest that policymakers in developed and developing economies increase productivity, resulting in higher labor productivity and energy efficiency and leading to more environmentally friendly industries.

The second group of variables in developing economies serves to aggravate CO₂ emissions; however, it has a negative effect in the case of developed economies. Renewable energy consumption has an effect on CO₂ emissions in developing economies completely opposite to that in developed economies. We can confirm that renewable energy has a positive effect on CO₂ emissions in developing countries. This phenomenon validates the EKC hypothesis and can be explained by the fact that solid biofuels for traditional use are the largest renewable sources for most of the developing economies in the G20; however, almost 0% of developed economies in the G20 use this traditional source of renewable energy. This finding implies that developing economies should change their energy structure by replacing more non-clean renewable energy with clean renewable energy, while policymakers in developed economies need to consider CO₂ emissions from a global perspective by extending advanced technology pertaining to renewable energy development to all countries.

This finding also demonstrates that as the economy grows, energy efficiency and clean energy technologies will improve, thus improving the environment and making secondary industry more environmentally friendly.

4.3.3. Tertiary Sector and CO₂ Emissions

The effects of the tertiary sector on CO₂ emissions can be divided into three groups. The first group comprises the variables that favor increasing CO₂ emissions in developing economies and decreasing CO₂ emissions in developed economies. Stock market capitalization (SMC) represents a government's policy orientation and market demand. Economic growth is supported mainly by higher productivity and higher energy efficiency in developed markets; thus, this demand will be reflected in the stock market. Moreover, developed

economies are more efficient and have strong stock markets in which the price of new technology and higher productivity will be directly reflected in share prices. Thus, the stock market itself is an energy efficiency filter; in contrast, developing economies focus more on the expansion of economic growth, not on CO₂ reduction. On the one hand, compared with that in a developed market, the price of new technology and higher productivity in a developing market needs time to ferment and does not have the ability to directly reflect share prices. Policymakers in developing economies need to increase the efficiency of their stock markets. Furthermore, a healthy financial system, including a healthy stock market, can help firms resolve funding issues in both the short term and the long term.

Both commercial service exports and imports show a positive relationship with CO₂ emissions in developing economies and a negative relationship in developed economies. This simultaneously validates the EKC hypothesis; as mentioned above, the commercial service gap between developing and developed economies was more than USD 1000 billion in 2018. This implies that information and communication technologies not only play an important role in economic growth but also help increase productivity in manufacturing industries, resulting in a reduction in CO₂ emissions. Policymakers in developing economies need to improve information and communications technology, facilitating infrastructure and fulfilling the need for training of skilled labor.

Additionally, exports show a positive relationship with CO₂ emissions in developing economies. This is because developing economies need more raw materials for manufacturing processes, and developed economies manufacture their products in developing economies. This finding implies that developing economies import CO₂ in exchange for economic growth.

The second group consists of variables related to stock trading value and imports, which are significantly positively related to CO₂ emissions in both developing and developed economies. Stock trading value is the total number of domestic and foreign shares traded, multiplied by their respective matching prices. The trading of stocks does not directly generate an increase in social wealth but is a transfer or reallocation of wealth among shareholders. Without a stock market, the value of an enterprise would be severely affected by its illiquidity. Thus, because a high trading value in stock would increase CO₂ emissions, we suggest that policymakers in both economies consider applying an environmental protection tax in proportion to the trading value.

The third group contains variables that work in favor of reducing CO₂ emissions in only one type of economy. FDI inflows have a negative impact on CO₂ emissions in developing economies, and FDI outflows have a negative impact on CO₂ emissions in developed economies. This finding can be interpreted to mean that FDI inflows bring new technology into host countries or direct imports of new technology into a country where the technology may not be available. However, this is not the case in developed economies, as they do not rely on FDI inflows for technology transfer and innovation. Moreover, these foreign investors might not pay much attention to emissions control during production. Therefore, we suggest that policymakers in developing economies attract more FDI inflows from developed economies by reducing taxes and paying benefits to GHG emission reduction projects. On the other hand, we suggest that policymakers in developed economies promote policies that convert FDI into clean and renewable energy projects.

As listed in Table 8, nearly all variables in the tertiary sector are positively related to CO₂ emissions in developing countries and negatively related to CO₂ emissions in developed countries. This simultaneously validates the EKC hypothesis. The tertiary sector in developed countries is fully resistant to environmental degradation by virtue of more advanced technology and better energy use efficiency.

Table 8. FMOLS long-run results for the three-sector model.

Variables	Developing Economies	Developed Economies
Primary sector		
AGR	+	–
Secondary sector		
IND	+	+
REC	+	–
NREC	+	+
Tertiary sector		
FDINI	-	null
FDINO	null	–
SMC	+	–
STV	+	+
EXP	+	null
IMP	+	+
COE	+	–
COI	+	–

These findings and policy suggestions address the research gap and illustrate that, as opposed to the many controversial validation formulas for determining the validity of EKC, the three-sector model of validation allows the effects of EKC to be combined with real industries to identify their patterns.

5. Conclusions

This study examined the validity of the EKC hypothesis by verifying the relevance of the three-sector model for developing and developed countries. The empirical findings of this study suggest that there is a significant long-run equilibrium relationship between the three sectors through 12 variables and CO₂ emissions. This finding implies that CO₂ emissions are closely related to primary, secondary, and tertiary sectors in the long run. The long-run CO₂ emissions elasticities indicate that the primary sector (agriculture) has a positive and negative effect on the CO₂ emissions in developing and developed economies, respectively. In the secondary sector, three variables show a positive relationship with the CO₂ emissions of developing economies: industry, nonrenewable energy consumption and renewable energy consumption; while for developed economies, there are two variables: industry and nonrenewable energy consumption. Except for FDI inflow, all variables in the tertiary sector for developing economies show a positive relationship with CO₂ emissions, including commercial service exports, commercial service imports, stock market capitalization, stock trading value, exports and imports. All variables in the tertiary sector of developed economies show a negative relationship with CO₂ emissions except for stock trading value and imports.

Furthermore, the EKC hypothesis has been confirmed. The relationship between the three sectors in the economy and carbon dioxide emissions shows opposite results for the developing and developed G20 countries. Developed countries, with their more advanced economies, production technologies, and clean energy technologies, better energy efficiency and more competitive stock markets, are well positioned to improve the environmental degradation caused by CO₂ emissions. This finding is direct evidence that economic development can improve the environment. Future research could be concentrated in the following areas: (1) expansion of the study beyond the G20 to more countries, regions and economic groupings; (2) extension of the research time interval; (3) the selection of

additional environmental indicators as dependent variables, i.e., NO₂, SO₂, PM diameter; and (4) the addition of more explanatory variables.

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Abbreviations

CO ₂	(carbon dioxide)
EKC	(Environment Kuznets Curve)
FDI	(foreign direct investment)
CDE	(CO ₂ emissions)
NREC	(nonrenewable energy consumption)
REC	(renewable energy consumption)
EXT	(export of goods and services)
IMT	(import of goods and services)
COE	(commercial service exports)
COI	(commercial service imports)
FDI	(foreign direct investment)
FDINI	(foreign direct investment net inflows)
FDINO	(foreign direct investment net outflows)
SMC	(stock market capitalization)
STV	(stock trade total value)
AGR	(Agriculture)
IND	(industry)
STIRPAT	(Stochastic Impacts by Regression on Population, Affluence and Technology)
CADF	(cross-section augmented Dickey-Fuller)
IPS	(Im et al. (2003) panel unit root test)
FMOLS	(Fully Modified ordinary least squares)

Notes

- ¹ $\ln(E/P)_{it} = \alpha_t + \beta_{1t}\ln(GDP/P)_{it} + \beta_{2t}(\ln(GDP/P)_{it})^2 + \varepsilon_{it}$. where E is the environmental indicator, i.e., CO₂ emissions (Shuai et al. 2017), water chemical oxygen and SO₂ emissions (Jayanthakumaran et al. 2012), biodiversity conservation and biological capacity (Mills and Waite 2009). P is the population of the specific study region. GDP is the gross domestic product of a specific study region and is used to indicate the level of income.
- ² Primary sector: agriculture; Secondary sector: industry, renewable energy, nonrenewable energy; Tertiary sector: export, import, FDI inflow, FDI outflow, commercial service exports, and commercial service imports, stock market capitalization, stock market trading value.
- ³ The data for 2014 will be used until this study is finalized.
- ⁴ According to the World Bank (2021), commercial services are defined as “the intangible product that is produced, transferred and consumed accompanied with economic output”.

- ⁵ (1) Data are from the World Bank database. (2) Data are missing for India for 2018.
- ⁶ (1) Data are from the World Bank database.
- ⁷ Data from 2014 will be used until this study is finalized; World Bank database. <https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?view=chart> (accessed on 10 June 2021).
- ⁸ None of the data used are percentages.
- ⁹ Nonrenewable energy consumption (NREC); renewable energy consumption (REC); export of goods and services (EXT); import of goods and services (IMT); commercial service exports (COE); commercial service imports (COI); foreign direct investment net inflows (FDINI); foreign direct investment net outflows (FDINO); agriculture (AGR); industry (IND); stock market capitalization (SMC); stock trade total value (STV).

References

- Abbasi, Kashif. Raza, Festus Fatai Adedoyin, Jaffar Abbas, and Khadim Hussain. 2021a. The impact of energy depletion and renewable energy on CO₂ emissions in Thailand: Fresh evidence from the novel dynamic ARDL simulation. *Renewable Energy* 180: 1439–50. [[CrossRef](#)]
- Abbasi, Kashif Raza, Muhammad Shahbaz, Zhilun Jiao, and Muhammad Tufail. 2021b. How energy consumption, industrial growth, urbanization, and CO₂ emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach. *Energy* 221: 119793. [[CrossRef](#)]
- Abdallah, Khaled Ben, Mounir Belloumi, and Daniel De Wolf. 2013. Indicators for sustainable energy development: A multivariate cointegration and causality analysis from Tunisian road transport sector. *Renewable Sustainable Energy Review* 25: 34–43. [[CrossRef](#)]
- Achchuthan, Sivapalan. 2013. Export, import and economic growth: Evidence from Sri Lanka. *Journal of Economics and Sustainable Development* 4: 147–55.
- Adebayo, Tomiwa Sunday, Gbenga Daniel Akinsola, Dervis Kirikkaleli, Festus Victor Bekun, Sukru Umarbeyli, and Oseyenbhin Sunday Osemeahon. 2021. Economic performance of Indonesia amidst CO₂ emissions and agriculture: A time series analysis. *Environmental Science and Pollution Research* 28: 47942–56. [[CrossRef](#)]
- Agbelie, Bismark R. D. K. 2016. Random-parameters analysis of energy consumption and economic output on carbon dioxide emissions. *Energy Systems* 7: 549–68. [[CrossRef](#)]
- Aghion, Philippe, and Peter Howitt. 1992. A model of growth through creative destruction. *Econometrica* 60: 323–51. [[CrossRef](#)]
- Ali, Yousaf. 2015. Measuring CO₂ emission linkages with the hypothetical extraction method (HEM). *Ecological Indicators* 54: 171–83. [[CrossRef](#)]
- Apergis, Nicholas, James E. Payne, Kojo Menyah, and Yemane Wolde-Rufael. 2010. On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. *Ecological Economics* 69: 2255–60. [[CrossRef](#)]
- Asongu, Simplice, Ghassen El Montasser, and Hassen Toumi. 2016. Testing the relationships between energy consumption, CO₂ emissions, and economic growth in 24 African countries: A panel ARDL approach. *Environmental Science and Pollution Research* 23: 6563–73. [[CrossRef](#)]
- Awokuse, Titus O. 2007. Causality between exports, imports, and economic growth: Evidence from transition economies. *Economics Letters* 94: 389–395. [[CrossRef](#)]
- Awokuse, Titus O. 2008. Trade openness and economic growth: Is growth export-led or import-led? *Applied Economics* 40: 161–73. [[CrossRef](#)]
- Awokuse, Titus O. 2009. Does agriculture really matter for economic growth in developing countries? Paper presented at 2009 Annual Meeting, Agricultural and Applied Economics Association (AAEA), Milwaukee, WI, USA, July 26–28.
- Aziz, Azlina Abd., Nik Hashim Nik Mustapha, and Roslina Ismail. 2013. Factors affecting energy demand in developing countries: A dynamic panel analysis. *International Journal of Energy Economics Policy* 3: 1–6.
- Bah, El-Hadj M. 2007. A Three-Sector Model of Structural Transformation and Economic Development. In *MPRA Paper*. Munich: University Library of Munich.
- Baiocchi, Giovanni, and Jan C. Minx. 2010. Understanding changes in the UK's CO₂ emissions: A global perspective. *Environmental Science & Technology* 44: 1177–84.
- Ball, Eldon V., Sun L. Wang, Richard Nehring, and Roberto Mosheim. 2016. Productivity and economic growth in U.S. agriculture: A new look. *Applied Economic Perspectives and Policy* 38: 30–49. [[CrossRef](#)]
- Barbieri, Laura. 2006. *Panel Unit Root Tests: A Review*. *Serie Rossa: Economia—Quaderno N. 43*. Piacenza: Università Cattolica del Sacro Cuore, pp. 1–53.
- Bekun, Festus Victor. 2022. Mitigating emissions in India: Accounting for the role of real income, renewable energy consumption and investment in energy. *International Journal of Energy Economics and Policy* 12: 188–92. [[CrossRef](#)]
- Ben Jebli, Mehdi, Slim Ben Youssef, and Nicholas Apergis. 2014. The Dynamic Linkage between Renewable Energy, Tourism, CO₂ Emissions, Economic Growth, Foreign Direct Investment, and Trade. *Latin American Economic Review* 28: 2. [[CrossRef](#)]
- Burck, Jan, Franziska Marten, and Christoph Bals. 2015. *The Climate Change Performance Index: Results 2016*. Berlin: Germanwatch.
- Crafts, Nicholas, and Terence C. Mills. 2017. Six centuries of British economic growth: A time-series perspective. *European Review of Economic History* 21: 141–58. [[CrossRef](#)]

- Davis, Steven J., and Ken Caldeira. 2010. Consumption-based accounting of CO₂ emissions. *Proceedings of the National Academy of Sciences of the United States of America* 107: 5687–92. [CrossRef]
- Dogan, Eyup, and Berna Turkekul. 2016. CO₂ emissions, real output, energy consumption, trade, urbanization and financial development: Testing the EKC hypothesis for the USA. *Environmental Science and Pollution Research* 23: 1203–13. [CrossRef]
- Dong, Kangyin, Gal Hochman, Yaqing Zhang, Renjin Sun, Hui Li, and Hua Liao. 2018. CO₂ emissions, economic and population growth, and renewable energy: Empirical evidence across regions. *Energy Economics* 75: 180–92. [CrossRef]
- Dudin, Mihail Nikolaevich, Yurievich Reshetov Konstantin, Ivanovich Mysachenko Victor, Nikolaevna Mironova Natalia, and Vladimirovna Diveenko Olga. 2017. Green technology and renewable energy in the system of the steel industry in Europe. *International Journal of Energy Economics Policy* 7: 310–15.
- Ehrlich, Pual R., and John P. Holdren. 1971. Impact of population growth. *Science* 171: 1212–17. [CrossRef]
- Ekanayake, E. M. 1999. Exports and economic growth in Asian developing countries: Cointegration and error-correction models. *The Journal of Development Economics* 24: 43–56.
- Fan, Hongzhong, Md Ismail Hossain, Mollah Aminul Islam, and Yassin Elshain Yahia. 2019. The impact of trade, technology and growth on environmental deterioration of China and India. *Asian Economic and Financial Review* 9: 1–29. [CrossRef]
- Fosu, Augustin Kwasi. 1990. Exports and economic growth: The African case. *World Development* 18: 831–35. [CrossRef]
- Fuchs, Victor R. 1965. The growing importance of the service industries. *The Journal of Business* 38: 344–73. [CrossRef]
- Gai, Qingen, Naijia Guo, Bingjing Li, Qinghua Shi, and Xiaodong Zhu. 2021. *Migration Costs, Sorting, and the Agricultural Productivity Gap*. Toronto: University of Toronto, Department of Economics.
- Ghosh, Sajal. 2002. Electricity consumption and economic growth in India. *Energy Policy* 30: 125–29. [CrossRef]
- Gibbs, David, and Keith Tanner. 2010. Information and communication technologies and local economic development policies: The British case. *Regional Studies* 31: 765–74. [CrossRef]
- Grossman, Gene M. 1995. Pollution and growth: What do we know? In *The Economics of Sustainable Development*. Edited by Ian Goldin and L. Alan Winters. Cambridge: Cambridge University Press, pp. 19–45.
- Guan, Dabo, Glen P. Peters, Christopher L. Weber, and Klaus Hubacek. 2009. Journey to world top emitter: An analysis of the driving forces of China's recent CO₂ emissions surge. *Geophysical Research Letters* 36: L04709. [CrossRef]
- Guerrieri, Paolo, and Valentina Meliciani. 2005. Technology and international competitiveness: The interdependence between manufacturing and producer services. *Structural Change and Economic Dynamics* 16: 489–502. [CrossRef]
- Hamory, Joan, Marieke Kleemans, Nicholas Y. Li, and Edward Miguel. 2021. Reevaluating agricultural productivity gaps with longitudinal microdata. *Journal of the European Economic Association* 19: 1522–55. [CrossRef]
- Huffman, Wallace E., and Peter F. Orazem. 2007. Agriculture and human capital in economic growth: Farmers, schooling and nutrition. *Handbook of Agricultural Economics* 3: 2281–341.
- Im, Kyung So, M. Hashem Pesaran, and Yongcheol Shin. 2003. Testing for unit roots in heterogeneous panels. *Journal of Economics* 115: 53–74. [CrossRef]
- IPCC. 2019. United Nations Environment Programme (UNEP) Emissions Gap Report. Available online: <https://www.unenvironment.org/resources/emissions-gap-report-2019> (accessed on 26 November 2019).
- Jayanthakumaran, Kankesu, Reetu Verma, and Ying Liu. 2012. CO₂ emissions, energy consumption, trade and income: A comparative analysis of China and India. *Energy Policy* 42: 450–60. [CrossRef]
- Katircioglu, Salih Turan. 2006. Causality between agriculture and economic growth in a small nation under political isolation. *International Journal of Social Economics* 33: 331–43. [CrossRef]
- Khan, Irfan, Fujun Hou, Abdulrasheed Zakari, and Vicent Konadu Tawiah. 2021. The dynamic links among energy transitions, energy consumption, and sustainable economic growth: A novel framework for IEA countries. *Energy* 222: 119935. [CrossRef]
- Kondo, Yoshinori, Yuichi Moriguchi, and H. Shimizu. 1998. CO₂ Emissions in Japan: Influences of imports and exports. *Applied Energy* 59: 163–74. [CrossRef]
- Leamer, Edward E., and Michael Storper. 2001. The economic geography of the internet age. *Journal of International Business Studies* 32: 641–65. [CrossRef]
- Lee, Chien Chiang, and Chun Ping Chang. 2008. Energy consumption and economic growth in Asian economies: A more comprehensive analysis using panel data. *Resource and Energy Economics* 30: 50–65. [CrossRef]
- Lee, Jung Wan. 2013. The contribution of foreign direct investment to clean energy use, carbon emissions and economic growth. *Energy Policy* 55: 483–89. [CrossRef]
- Leitao, Nuno Carlos. 2014. Economic growth, carbon dioxide emissions, renewable energy and globalization. *International Journal of Energy Economics Policy* 4: 391–99.
- Lenton, Timothy M., Johan Rockström, Owen Gaffney, Stefan Rahmstorf, Katherine Richardson, Will Steffen, and Hans Joachim Schellnhuber. 2019. Climate tipping points—Too risky to bet against. *Nature* 575: 592–95. [CrossRef]
- Li, You, and C. Nick Hewitt. 2008. The effect of trade between China and the UK on national and global carbon dioxide emissions. *Energy Policy* 36: 1907–14. [CrossRef]
- Li, Zhaoling, Minghao Jin, and Jianwei Cheng. 2021. Economic growth of green agriculture and its influencing factors in china: Based on emergy theory and spatial econometric model. *Environment, Development and Sustainability* 23: 15494–512. [CrossRef]
- Liu, Jun, Liang Liu, Yu Qian, and Shunfeng Song. 2021. The effect of artificial intelligence on carbon intensity: Evidence from China's industrial sector. *Socio-Economic Planning Sciences* 83: 101002. [CrossRef]

- Mahadevan, Renuka. 2003. Productivity growth in Indian agriculture: The role of globalization and economic reform. *Asia-Pacific Development Journal* 10: 57–72. [\[CrossRef\]](#)
- Manuel, A. Zambrano Monserrate, Valverde Bajana Ivanna, Aguilar Bohorquez Joseph, and Mendoza Jimenez María. 2016. Relationship between economic growth and environmental degradation: Is there an environmental evidence of Kuznets curve for Brazil? *International Journal of Energy Economics Policy* 6: 208–16.
- McMillan, Margaret, and Dani Rodrik. 2011. *Globalization, Structural Change and Productivity Growth*. NBER Working Papers 17143. Cambridge: National Bureau of Economic Research.
- Mills, Julianne H., and Thomas A. Waite. 2009. Economic prosperity, biodiversity conservation, and the environmental Kuznets curve. *Ecological Economics* 68: 2087–95. [\[CrossRef\]](#)
- Mohsin, Muhammad, Farhad Taghizadeh-Hesary, Nisit Panthamit, Saba Anwar, Qaiser Abbas, and Xuan Vinh Vo. 2021. Developing low carbon finance index: Evidence from developed and developing economies. *Finance Research Letters* 43: 101520. [\[CrossRef\]](#)
- Morsy, Hanan, Antoine Levy, and Clara Sanchez. 2015. *Growing without Changing: A Tale of Egypt's Weak Productivity Growth*. Working Paper No. 172. London: European Bank for Reconstruction and Development.
- Muangthai, Isara, Sue J. Lin, and Charles Lewis. 2016. Inter-industry linkages, energy and CO₂ multipliers of the electric power industry in Thailand. *Aerosol and Air Quality Research* 16: 2033–47. [\[CrossRef\]](#)
- Naseem, Snovia, and Guang Ji Tong. 2021. A system-GMM approach to examine the renewable energy consumption, agriculture and economic growth's impact on CO₂ emission in the SAARC region. *GeoJournal* 86: 2021–33. [\[CrossRef\]](#)
- Odetola, Tolulope, and Chinonso Etumnu. 2013. Contribution of agriculture to economic growth in Nigeria. Paper presented at the 18th Annual Conference of the African Econometric Society (AES) Accra, Ghana at the Session organized by the Association for the Advancement of African Women Economists (AAWE), Accra, Ghana, July 22–23.
- Oluwole, Israel Oliwasani, Paulinus Ikechukwu Attama, Fidelia Nebechi Onuigbo, and Ichaba Atabo. 2021. Agriculture: A panacea to economic growth and development in Nigeria. *Journal of Economics and Allied Research* 6: 134–46.
- Orhan, Ayhan, Tomiwa Sunday Adebayo, Sema Yilmaz Genç, and Dervis Kirikkaleli. 2021. Investigating the linkage between economic growth and environmental sustainability in India: Do agriculture and trade openness matter? *Sustainability* 13: 4753. [\[CrossRef\]](#)
- Ozcan, Burcu, and Recep Ulucak. 2021. An empirical investigation of nuclear energy consumption and carbon dioxide (CO₂) emission in India: Bridging IPAT and EKC hypotheses. *Nuclear Engineering and Technology* 53: 2056–65.
- Panayotou, Theodore. 1993. *Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development*. Working paper No. 292778. Geneva: International Labour Organization.
- Paramati, Sudharshan Reddy, Md Samsul Alam, and Ching-Fu Chen. 2016. The effects of tourism on economic growth and CO₂ emissions: A comparison between developed and developing economies. *Journal of Travel Research* 56: 712–24. [\[CrossRef\]](#)
- Paramati, Sudharshan Reddy, Di Mo, and Rakesh Gupta. 2017. The effects of stock market growth and renewable energy use on CO₂ emissions: Evidence from G20 countries. *Energy Economics* 66: 360–71. [\[CrossRef\]](#)
- Parikh, Jyoti, Manoj Panda, A. Ganesh-Kumar, and Vinay Singh. 2009. CO₂ emissions structure of Indian economy. *Energy* 34: 1024–31. [\[CrossRef\]](#)
- Pesaran, M. Hashem. 2003. A simple panel unit root test in the presence of cross section dependence. *Journal of Applied Econometrics* 22: 265–312. [\[CrossRef\]](#)
- Pie, Laia, Laura Fabregat-Aibar, and Marc Saez. 2018. The influence of imports and exports on the evolution of greenhouse gas emissions: The case for the European Union. *Energies* 11: 1644. [\[CrossRef\]](#)
- Raskin, Paul D. 1995. Methods for estimating the population contribution to environmental change. *Ecological Economics* 15: 225–33. [\[CrossRef\]](#)
- Riti, Joshua Sunday, and Yang Shu. 2016. Renewable energy, energy efficiency, and eco-friendly environment (R-E5) in Nigeria. *Energy, Sustainability and Society* 6: 1–16. [\[CrossRef\]](#)
- Roca, Jordi, Emilio Padilla, Mariona Farré, and Vittorio Galletto. 2001. Economic growth and atmospheric pollution in Spain: Discussing the environmental Kuznets curve hypothesis. *Ecological Economics* 39: 85–99. [\[CrossRef\]](#)
- Romano, Antonio Angelo, and Giuseppe Scandurra. 2013. Investments in renewable energy sources: The relationship with nuclear power consumptions. *Statistica* 73: 341–52.
- Roncolato, Leanne, and David Kucera. 2013. Structural drivers of productivity and employment growth: A decomposition analysis for 81 countries. *Cambridge Journal of Economics* 38: 399–424. [\[CrossRef\]](#)
- Ruttan, Vernon W. 2002. Productivity growth in world agriculture: Sources and constraints. *Journal of Economic Perspectives* 16: 161–84. [\[CrossRef\]](#)
- Sánchez-Chóliz, Julio, and Rosa Duarte. 2004. CO₂ emissions embodied in international trade: Evidence for Spain. *Energy Policy* 32: 1999–2005. [\[CrossRef\]](#)
- Sauerbeck, Dieter R. 2001. CO₂ emissions and C sequestration by agriculture—Perspectives and limitations. *Nutrient Cycling in Agroecosystems* 60: 253–266. [\[CrossRef\]](#)
- Shafaeddin, Mehdi S. 2004. Is China's accession to WTO threatening exports of developing countries? *China Economic Review* 15: 109–44. [\[CrossRef\]](#)
- Shafiei, Sahar, and Ruhul A. Salim. 2014. Non-renewable and renewable energy consumption and CO₂ emissions in OECD countries: A comparative analysis. *Energy Policy* 66: 547–56. [\[CrossRef\]](#)

- Shen, Jim Huangnan, Zhiming Long, Chien Chiang Lee, and Jun Zhang. 2022. Comparative advantage, endowment structure, and trade imbalances. *Structural Change and Economic Dynamics* 60: 365–75. [CrossRef]
- Shahbaz, Muhammad, and Avike Sinha. 2019. Environmental Kuznets curve for CO₂ emissions: A literature survey. *Journal of Economic Studies* 46: 106–68. [CrossRef]
- Shahbaz, Muhammad, Sakiru Adebola Solarin, Hairder Mahmood, and Mohamed Arouri. 2013. Does financial development reduce CO₂ emissions in Malaysian economy? A time series analysis. *Economic Model* 35: 145–52. [CrossRef]
- Shuai, Chenyang, Xi Chen, Liyin Shen, Liudan Jiao, Ya Wu, and Yongtao Tan. 2017. The turning points of carbon Kuznets curve: Evidences from panel and time-series data of 164 countries. *Journal of Cleaner Production* 162: 1031–47. [CrossRef]
- Shui, Bin, and Robert C. Harriss. 2006. The role of CO₂ embodiment in US–China trade. *Energy Policy* 34: 4063–68. [CrossRef]
- Soylu, Özgür Bayram, Tomiwa Sunday Adebayo, and Dervis Kirikkaleli. 2021. The imperativeness of environmental quality in China amidst renewable energy consumption and trade openness. *Sustainability* 13: 5054. [CrossRef]
- Spetan, Khawlah Ali Ahmed Adballa. 2016. Renewable energy consumption, CO₂ emissions and economic growth: A case of Jordan. *International Journal of Business and Economics Research* 5: 217–26. [CrossRef]
- Stacey, James. 2008. Multi-dimensional risk and mean-kurtosis portfolio optimization. *Journal of Financial and Quantitative Analysis* 21: 47–56.
- Stern, David I. 2004. The rise and fall of the environmental Kuznets curve. *World Development* 32: 1419–39. [CrossRef]
- Talbi, Besma. 2017. CO₂ emissions reduction in road transport sector in Tunisia. *Renewable and Sustainable Energy Reviews* 69: 232–38. [CrossRef]
- Timmer, Ptter C., and Selvin Akkus. 2008. *The Structural Transformation as a Pathway out of Poverty: Analytics, Empirics and Politics*. CGD Working Paper 150. Washington, DC: Center for Global Development (CGD).
- Tunç, G. İpek, Serap Türüt-Aşık, and Elif Akbostancı. 2007. CO₂ emissions vs. CO₂ responsibility: An input–output approach for the Turkish economy. *Energy Policy* 35: 855–68. [CrossRef]
- Ugur, Ahmet. 2008. Import and economic growth in Turkey: Evidence from multivariate VAR analysis. *Journal of Economics and Business* 11: 54–75.
- UN-Water. 2020. *United Nations World Water Development Report 2020: Water and Climate Change*. Paris: UNESCO.
- Webb, Patrick, and Steven Block. 2012. Support for agriculture during economic transformation: Impacts on poverty and undernutrition. *Proceedings of the National Academy of Sciences of the United States of America* 109: 12309–14. [CrossRef] [PubMed]
- Weber, Christopher L., and H. Scott Matthews. 2007. Embodied environmental emissions in U.S. international trade, 1997–2004. *Environmental Science & Technology* 41: 4875–81.
- Wee, Jung Ho, and Kyoung Sik Choi. 2010. CO₂ emission and avoidance in mobile applications. *Renewable and Sustainable Energy Reviews* 14: 814–20. [CrossRef]
- Wiedmann, Thomas, Richard Wood, Jan C. Minx, Manfred Lenzen, Dabo Guan, and Rocky Harris. 2008. A carbon footprint time series of the UK—Results from a multi-region input–output model. *Economic Systems Research* 22: 19–42. [CrossRef]
- World Bank. 2021. Data Indicators from the Website of the World Bank. Available online: <https://data.worldbank.org/indicator> (accessed on 10 June 2021).
- Wu, Weihong, Liying Sheng, Fangcheng Tang, Aimei Zhang, and Jia Liu. 2021. A system dynamics model of green innovation and policy simulation with an application in Chinese manufacturing industry. *Sustainable Production and Consumption* 28: 987–1005. [CrossRef]
- Yan, Yun Feng, and Lai Ke Yang. 2010. China’s foreign trade and climate change: A case study of CO₂ emissions. *Energy Policy* 38: 350–56.
- Yang, Zhenbing, Shuai Shao, Lili Yang, and Zhuang Miao. 2018. Improvement pathway of energy consumption structure in China’s industrial sector: From the perspective of directed technical change. *Energy Economics* 72: 166–76. [CrossRef]
- Yao, Shujie. 2010. How important is agriculture in China’s economic growth? *Oxford Development Studies* 28: 33–49. [CrossRef]
- Yasin, Iftikhar, Nawaz Ahmad, and M. Aslam Chaudhary. 2020. Catechizing the environmental-impression of urbanization, financial development, and political institutions: A circumstance of ecological footprints in 110 developed and less-developed countries. *Social Indicators Research* 147: 621–49. [CrossRef]
- York, Richard, Eugene A. Rosa, and Thomas Dietz. 2003. STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics* 46: 351–65. [CrossRef]
- Yuan, Rong, Paul Behrens, and Joao F. D. Rodrigues. 2017. The evolution of inter-sectoral linkages in China’s energy-related CO₂ emissions from 1997 to 2012. *Energy Economics* 69: 404–17. [CrossRef]
- Zhang, Xing Ping, and Xiao Mei Cheng. 2009. Energy consumption, carbon emissions, and economic growth in China. *Ecological Economics* 68: 2706–12. [CrossRef]
- Zhao, Yibing, Can Wang, Yuwei Sun, and Xiangbing Liu. 2018. Factors influencing companies’ willingness to pay for carbon emissions: Emission trading schemes in China. *Energy Economics* 75: 357–67. [CrossRef]