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A Decomposition Analysis of Carbon Emissions from Energy Use in Pakistan: The Application of Additive Logarithmic Mean Divisia Index and Tapio Decoupling Elasticity Approach

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Abstract
To reduce carbon emissions and mitigate their effects on climate change, it is essential to understand the sources that contribute to these emissions. This study aims at examining the factors driving carbon emissions in Pakistan from 1990 to 2019 by applying Additive Logarithmic Mean Divisia Index-1 decomposition approach. The results reveal that population size and affluence both contribute significantly to rising carbon emissions over time. This indicates that as the population grows and people become more affluent, they consume more energy, which results in increased carbon emissions. The aggregate impact of population size on carbon emissions increased to 12.92 Mtons from 1990-2019, far greater than the impact of other factors. Pakistan also experienced economic activity per person growth as a significant contributing factor to increasing emissions; the trend increased annually, and the cumulative effect reached 8.78 Mtons in 2019. Carbon intensity and renewable energy penetration contribute positively to carbon emissions, indicating a falling share of renewable energy. Contrary to this, the energy intensity effect is nearly stable during the period of analysis. The fuel-switching effect, however, is found to reduce carbon emissions. Moreover, Tapio's decoupling status reveals that Pakistan has faced four out of eight decoupling states during the period of analysis. The most notable among them is the expansive negative decoupling state (as $\eta > 1.2$), which points towards a much faster increase in emissions than GDP growth. Carbon emissions due to the use of bituminous coal have increased significantly since 2013. Overall, the study suggests that if a country's GDP growth rate is low and carbon emissions are high, the country should pursue concessional international climate finance and sponsors to invest in green technologies and national capital restoration programs.

Keywords: Carbon Emissions; Economic Growth; Population; Renewable Energy

JEL Classification: F64, O47, Q56, Q2

1. Introduction

The progression of mankind over the last several decades has resulted in increasingly adverse climate changes and natural calamities (Correia, 2019; Abbas & Andlib, 2026). The actions of people have harmed the environment, putting the survival of the current and future generations in jeopardy (Kono, 2014). Because of these circumstances, there has been a clear indication of a change in behavior with the intention of more efficient use of all resources, which will ensure less pressure on the environment (United Nations, 1972). This kind of responsible conduct is what could secure the long-term utilization of scarce resources to achieve the goal of sustainable development (Farsi et al., 2017; Andlib et al., 2024).

The spirit of the term sustainable economic development is deduced from the Triple Bottom Line (TBL) theory, which entails an integrity between three pillars of sustainability; (1) economic sustainability is needed to preserve the natural, man-made, and human capital necessary for providing job opportunities and maintaining living standards for people; (2) social sustainability, which ensures human rights, equality, and cultural identity. It is required to preserve respect for gender, race, religion and, cultural diversity; (3) environmental sustainability, which stresses on preserving the quality of the environment essential for smooth conduct of economic activities in every sector of the economy (Elkington, 1997).

Since the introduction of the term sustainable development, there has been a great debate about how growth and climate stability can coexist as nations move toward low-carbon economies. The emerging development patterns of 21 nations—including Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Netherlands, Portugal, Romania, Slovakia, Spain, Uzbekistan, UK, and USA—that have reduced GHG emissions while increasing GDP are used to support this argument (Aden, 2016). The World Resources Institute claims that since the start of the twenty-first century, these 21 nations have made great strides in their economic development while lowering yearly GHG emissions. The majority of these countries' decoupling of GDP and GHGs shows the viability and rising popularity of the switch towards clean methods of economic activity.

The environmental damage and climate crisis that Pakistan is going through have gained importance against the backdrop of rapid economic growth. An increase in energy consumption accompanies the country's economic expansion. Because of fossil fuel consumption, carbon emissions increased exponentially to 234.75Mt in 2020 since 1990 (Ritchie, Roser & Rosado, 2020). The IPCC-AR5 RCP scenarios predicted that by the end of the current century, these emissions will cause Pakistan's mean temperature to rise by about 1°C over the global average temperature. The World Bank has also warned that Pakistan's GDP could be reduced by 18 to 20% by 2050 due to extreme weather conditions, environmental degradation, and air pollution, which could impede progress on economic development. Therefore, to achieve the goal of economic development and environmental protection, it is essential to reduce carbon emissions.

Pakistan's economy has undergone tremendous expansion since the 1990s. This advancement has been accompanied by greater energy consumption. The economy of the country is primarily composed of three major sectors of activity. Agriculture, as a significant contributor to GDP, accounting for 22.7% of GDP. Labor Force Survey 2020-21 highlights that the agriculture sector employed 37.4% of the workforce in 2020-21. The agriculture sector is mostly dependent on cotton and textile exports. Manufacturing dominates the industrial sector in Pakistan, accounting for 12.4% of the GDP, including FBT (food, beverages, and tobacco), coke, petroleum, and pharmaceuticals, and employs 14.9% workforce. The services sector of Pakistan contributes over half of the GDP, and it is expanding day by day. Information and communication technology, business services, government services, travel, and tourism are the major sub-sectors of services in Pakistan. Rising energy demand from growing production activities resulted in an increase in total primary energy requirement as well as changes in the fuel share, and concurrently, a considerable rise in energy-related emissions.

According to Butt et al. (2021), carbon emissions in Pakistan jumped from 66 MT in 1990–91 to 203 MT in 2018–19. Energy-related carbon emissions climbed to 234.75Mt in 2020, 29% more than in 1990 (Ritchie et al. 2020), demonstrating the importance of green energy penetration in the country's emission mitigation efforts. Also, the country experienced a 0.6°C increase in mean temperature over the last century. Similarly, mean annual precipitation has increased in nearly every region of the country. In this case, the Ministry of Climate Change of the country has taken multiple measures toward a sustainable and clean future by reducing carbon emissions. Pakistan is a signatory to both the Montreal Protocol and the Vienna Convention for the Protection of the Ozone Layer. The Ministry of Climate Change has formed a National Ozone Unit to oversee the Montreal Protocol's implementation. Using a multifaceted action plan that included trade restrictions on ozone-depleting compounds, awareness campaigns, capacity-building initiatives, and technology transfer, Pakistan was able to phase out 10% of Hydrochlorofluorocarbons (HCFCs) in January 2015 as per the deadline.

Pakistan should move towards a low-carbon economy in the long run. Additionally, the promotion of the clean energy sector needs to be tied with international obligations of Intended Nationally Determined Contributions (INDs), under the Paris Agreement, and SDGs, as renewable energy is particularly significant for Pakistan since it is central to its energy policies for mitigating climate change. In this regard, understanding renewable energy penetration effects on carbon emissions is essential for national climate policies, and it may be of much interest to other developing and transition economies like Pakistan. Therefore, this study makes it possible by contributing to the existing knowledge by analyzing the renewable energy penetration effect on carbon emissions from a pure sustainability perspective. In this way, the study sought to improve the knowledge of the contributing factors of carbon emissions in Pakistan.

The main research focus of the current study is to decompose the quantitative relationship of carbon emissions with its driving forces, including fuel quality, energy efficiency, renewable energy penetration, energy intensity, economic activity per capita, and population size by applying the Kaya identity model and Additive Log Mean Divisia Index-I (LMDI-1) for Pakistan from 1990 to 2019. Moreover, this study further enhances the existing literature on decoupling states of Pakistan by providing long-term trends of the absolute contribution of the burning of fossil fuels (natural gas, bituminous coal, lignite, fuel oil, gas/diesel, kerosene, motor gasoline, LPG, and other oil products) to annual carbon emissions between 1990 and 2019. This perspective is particularly important because the share of these fuel consumption has changed during the period of analysis. The structure of the current study is as follows. After Section 1, Section 2 reviews the existing literature that is pertinent to the study. Data and variables used in this study are presented in Section 3. Section 4 contains the methodology and specifications of the model. Section 5 describes the empirical findings of the study. Finally, Section 6 concludes the study and provides important policy implications.

2. Literature Review

Carbon emissions have an adverse impact on economic development in multiple ways. High levels of carbon emissions can lead to extreme weather events and natural disasters. A climate-driven catastrophe struck Pakistan in the summer of 2022 on a scale that had never been experienced in this region. After prolonged droughts, the monsoon season provided more than three times the usual amount of rain. Following the flooding, 10% of the land was submerged, around 33 million people were affected, around 7 million dwellings were demolished, and about 1400 individuals lost their lives (Wyns, 2022). Pakistan is ranked eighth out of the ten most vulnerable countries to climate change (Eckstein, Künzel & Schäfer, 2021). According to the report, from 2000 to 2019, Pakistan faced 173 adverse weather events, lost 0.52 per GDP unit, and experienced around 0.3 fatalities per 100,000 inhabitants. The impacts of climate change can harm economic development by reducing agricultural productivity in the country, disrupting the supply chain, and damaging economic activities (Awan & Yaseen, 2017; Syed et al., 2022). With just a one degree Celsius rise in temperature, Pakistan's wheat production is anticipated to reduce by 6 to 9%, and even a smaller rise will have a substantial impact on profitable crops like cotton and mango (Mustafa, 2011).

Additionally, carbon emissions can lead to air and water pollution, which increases healthcare expenditures and decreases human productivity in Pakistan (Malik, Awan & Khan, 2012). Carbon dioxide from fossil fuel burning has increased mortality and severe cases of tuberculosis, which represents an alarming situation for human capital (Asghar et al., 2020). Furthermore, the costs of adapting to a changing climate are also high in Pakistan. The coefficient of temperature in the long difference model showed that a rise in temperature of 1°C would result in an increase in overall government spending of

0.62% (Bakhsh et al., 2021). Shahid & Piracha (2016) described in their study that unawareness of local officials and lack of government interest in climate change adaptation, political instability, fragile economic conditions of Pakistan, and lack of planning are the main barriers to developing and putting into practice climate change adaptation.

Human activities play an important role in the economic development of a country (Ahmad et al., 2020; Beyene, 2022). It has been shown that human activities such as entrepreneurship, innovation, and investment in ICT are the main drivers of the long-run growth of Pakistan (Syed & Bukhari, 2019; Rahman et al., 2021). All these activities lead to the improvement in infrastructure, transportation, and the industrial sector, which have created jobs and increased income for many citizens. However, these activities have also contributed to the rise in emissions within the country. Similarly, human activities such as industrialization and modern society have also contributed significantly to driving the economic growth of the country.

For the period 1980 to 2018, Khan & Majeed (2023) found that Pakistan experienced expansive negative decoupling for many years. Industrial development and economic growth are the factors that weaken decoupling progress in Pakistan. In another study for Pakistan, Khan & Majeed (2019) employed Tapio's elasticity approach and found that carbon intensity and energy intensity are two major factors of decoupling; on the other hand, economic growth and energy structure restrict it. Similarly, Lin and Ahmad (2017) also applied the LMDI approach and found that economic growth and population size are the leading factors of carbon emission in Pakistan. The burning of fossil fuels and the expansion of industries have led to the release of GHGs that contribute to climate change in Pakistan (Attari, Hussain & Javid, 2016). Similarly, using modern appliances and having little or no knowledge of energy efficiency or conservation emits heat and other harmful gases, such as carbon emissions, into the environment in Pakistan (Aslam, Nazir & Zia, 2021).

The Kyoto Protocol operationalizes the United Nations Framework Convention on Climate Change through the commitment of industrialized economies and countries in transitory phase to limiting and reducing their GHGs emissions. Pakistan ratified the Kyoto Protocol on 11 January 2005, after adopting it in 1997 (Government of Pakistan, 2008). Anser et al. (2020) examined the UN Sustainable Development Goals (SDGs) for Pakistan from 1970 to 2016 by employing Tapio's elasticity approach. The study identified weak, expansive negative, and strong decoupling states between water-energy-food resources and carbon-fossil-greenhouse gas emissions across different time periods. The results highlighted the need to reduce carbon-fossil-greenhouse gas emissions in water-energy-food resources through environmentally friendly technologies.

Pakistan's contribution to the world's carbon emissions climbed from 0.3% annually in 1990 to 0.67% in 2020, despite being a relatively small contributor to the total GHGs (Ritchie et al., 2020). Fossil fuels, such as coal, oil, and natural gas, are the major sources of GHGs in Pakistan. Over the past 20 years, carbon emissions in Pakistan from the fossil fuel burning, such as oil, gas, and coal, have more than doubled (Butt et al., 2021). According to the Government of Pakistan (2019), fossil fuel consumption and economic growth are tightly bound with each other. Additionally, the increasing demand for energy in the country has increased the demand for fossil fuels, further accelerating the problem.

The industrial sector – at 32% is the largest participant in energy-related carbon emissions, followed by transport and electricity at 28% and 27% respectively (Climate Transparency, 2020). Rasheed et al. (2022) applied an additive LMDI approach using the Kaya identity to analyze the cement manufacturing sector in Pakistan from 2005 to 2020. The study's findings indicated that Pakistan's cumulative carbon emissions continue to rise, with a slight decline during 2011–2012. Moreover, energy intensity is the primary driver, and carbon intensity is the second most important factor. In parallel lines, Xiuhui & Raza (2022), 1990-2019 applied Tapio's elasticity and found that workers' effect, energy intensity, and energy structure of Pakistan are major factors in causing a 133.40 Mt increase in CO2Es during 1990-2019. Moreover, five decoupling states were identified, and the expansive negative decoupling was higher during the whole period of analysis.

According to Mahmood & Shahab (2014), coal consumption in the cement industry increased by 61% since 2001. The transport sector is the major oil consumer in the country. It is mainly due to the growth in motorized vehicles after 2001. In terms of installed capacity, hydro generation makes up 29% of the power industry, while thermal generation makes up 61%. The contributions from wind, solar, bagasse, and nuclear power are 3%, 1%, 1%, and 4%, respectively (National Transmission and Dispatch Company, 2019). Due to these reasons, a paradigm shift is needed where income grows without causing a significant increase in natural resource consumption to avoid atmospheric pollution (Jabeen & Khan, 2022). Raza, Chen & Tang (2022) applied additive LMDI for 1993-2017 and found that raising research and development investments, and technology transfer are the approaches to a cleaner environment and sustained economic development of Pakistan. Furthermore, the study recommended that the reduction in energy intensity has a positive impact on sustainable economic growth and the environment.

3. Data and Variables

The objectives of the study are examined over the 1990-2019 time span, for which time series data for population, GDP, and energy are available.

Table 1: Variables Included in the Dataset

Variable	Unit	Data Source
Fossil fuel consumption by fuel type	TJ	International Energy Agency
Total fossil fuel consumption	TWh	Our World in Data
Total primary energy consumption	TWh	Our World in Data
Gross Domestic Product	Constant 2010 US$	Our World in Data
Population	Total	Our World in Data

The annual data for numerous fossil fuel types of natural gas, coal, and oil are collected from the International Energy Agency, an independent intergovernmental organization established in 1974 as a section of the OECD in the wake of the 1973 oil crisis. Annual data for various non-OECD Asian nations, including Pakistan, are included in the database of world energy balances for the years 1971 through 2019. The sub-eight kinds of fuel, including other bituminous coal, lignite, fuel oil, gas/diesel, other kerosene, motor gasoline, LPG, and other oil products, along with natural gas, make up the fossil fuels data.

Our World in Data (OWID), a scientific data publishing website, uses official information from the UN and other international organizations to compile data on the global fossil fuel and primary energy consumption. Therefore, total fossil fuels consumption and primary energy consumption data are collected from OWID. Energy used from all sources of coal, oil, and gas is included in the total amount of fossil fuel consumption. Petroleum, coal, gasoline, nuclear energy, hydel, wind power, solar, and other types of renewable energy are all included in the total primary energy consumption. Biomass, geothermal, and waste energy are included in other renewable energy sources. Gross Domestic Product (GDP) at constant 2010 prices is gathered from OWID. In order to account for pricing variations among countries and inflation over time, GDP is expressed in dollars using 2010 prices. Services, industry, and agriculture sectors are all included in the GDP at constant 2010 prices.

Estimates of the population are collected from OWID based on the de facto definition of the population, which includes all citizens regardless of their nationality. Since 1950, OWID has kept a dataset of population statistics broken down by nation, region, and the whole world. By adopting a constant population growth rate between two data points, the population numbers are adjusted for mid-year (July 1). The population data is extrapolated or interpolated for the years for which national estimates are unavailable. The projections are based on July 1 of a certain year. Time series population calculates the population's size.

The following equation is used to estimate the carbon emissions according to the 2006 IPCC national guidelines on greenhouse gas inventories.

$$C_i^t = FF_i^t \times EF_i$$

$$C_{tot}^t = \sum_{i}^{n=9} FF_i^t \times EF_i$$

$FF_i^t \times EF_i$ is the total quantity of i^{th} type of fossil fuel consumption in the time period t times the carbon emission factor of that fossil fuel. C_i^t denotes the total carbon emission factors from i^{th} fossil fuel for time period t. C_{tot}^t is the amount of total carbon emissions in the t time period. In Table 2 below, carbon emission factors for fuel type i are listed.

Table 2: Carbon Emission Factors from Various Fuels

Fossil Fuel	**Fuel (i)**	**Carbon Emissions [(KG/TJ)^2]**
Natural Gas	Natural Gas	56100
Coal	Other Bituminous coal	94600
	Lignite	101000
Petroleum	Fuel Oil	77400
	Gas/ Diesel	74100
	Other Kerosene	71900
	Motor Gasoline	69300
	LPG	61600
	Other Oil Products	73300

Source: *Intergovernmental Panel on Climate Change (2006)*

4. Methodology

The most applied index decomposition analyses are the Laspeyres, Paasche, Generalized Fisher Index, Logarithmic Mean Divisia Index, and Arithmetic Mean Divisia Index. Laspeyres, Paasche, and AMDI methods have obvious drawbacks. The AMDI decomposition approach does not satisfy the factor reversal test, which means that it is not applicable for complete decomposition, as it leaves a residual term. Similarly, Laspeyres and Paasche's decomposition methods do not pass the time-reversal test and factor reversal test. Both methods induce the residual term, which is rather significant. The generalized Fisher index can be a better choice as it possesses more desirable properties as compared with other widely used indices. However, the limitation of the generalized Fisher index is that its formula becomes relatively complex when it is extended for "n" factors. Ang, Liu & Chung (2004) believe that even if a decomposition approach possesses most of the properties, it may not be quite effective in case the formula under consideration is too complicated. Our dataset contains no negative or zero values for the variables of population, GDP, fossil fuel consumption, and carbon emissions. In such a case, the LMDI decomposition can be a good practical application for the model of the current study.

The Kaya model is the most commonly used to estimate carbon emissions nationally. The basic idea behind this model, which Kaya (1990) originally presented to the IPCC, is to express carbon emissions in accordance with four key factors as illustrated in the following equation.

$$C = \frac{C}{E} \times \frac{E}{GDP} \times \frac{GDP}{P} \times P$$

Where P stands for population, GDP denotes gross domestic product. Similarly, E and C stand for energy consumption and total carbon emissions, respectively. To evaluate the variations in carbon emissions from energy consumption in Pakistan, the Kaya identity has been expanded as follows:

$$C_{tot} = \sum_{i}^{n} C_i = \sum_{i} (\frac{C_i}{FF_i}) \times (\frac{FF_i}{T^{ff}}) \times (\frac{T^{ff}}{TE}) \times (\frac{TE}{E}) \times (\frac{E}{P}) \times P$$

$$C = F \times R \times V \times I \times G \times P \qquad \text{Eq. (1)}$$

In Eq. (1) above, $C, C_i, FF_i, T^{ff}, TE, E \; and \; P$ represent total carbon emissions, carbon emissions due to fossil fuel type *i, the* fossil fuel consumption of type *i,* total fossil fuels consumption, total primary energy consumption, economic output, and total population size, respectively.

$F = \frac{C_i}{FF_i}$ is the carbon intensity factor, $R = \frac{FF_i}{T^{ff}}$ is the effect of fossil fuel *i* consumption in total fossil fuels, $V = \frac{T^{ff}}{TE}$ is the effect of total fossil fuels consumption in total primary energy, $I = \frac{TE}{E}$ is the energy intensity effect, $G = \frac{E}{P}$, is the economic activity and *P* is the population size effect.

Similarly, the following formula can be used to express changes in emissions from a base period (0) to a target period (t):

$$\Delta C_{tot} = C^t - C^0 = \Delta C_F + \Delta C_R + \Delta C_V + \Delta C_I + \Delta C_G + \Delta C_P$$

$$\Delta C_F = \sum_i W_i \times \ln\left\{\frac{F^t}{F^0}\right\}$$

$$\Delta C_R = \sum_i W_i \times \ln\left\{\frac{R^t}{R^0}\right\}$$

$$\Delta C_V = \sum_i W_i \times \ln\left\{\frac{V^t}{V^0}\right\}$$

$$\Delta C_I = \sum_i W_i \times \ln\left\{\frac{I^t}{I^0}\right\}$$

$$\Delta C_G = \sum_i W_i \times \ln\left\{\frac{G^t}{G^0}\right\}$$

$$\Delta C_P = \sum_i W_i \times \ln\left\{\frac{P^t}{P^0}\right\}$$

Where $\sum_{\boldsymbol{i}} W_i = \sum_{\boldsymbol{i}} \frac{\boldsymbol{C_i^t - C_i^0}}{\boldsymbol{lnC_i^t - lnC_i^0}}$ $\quad i = 1,2, \ldots, 9$

The Environmental Kuznets Curve (EKC) is a prominent method for analyzing environmental performance, implying that environmental degradation first worsens with economic expansion but begins to improve after a specific income threshold level. However, the concept of decoupling economic growth and environmental deterioration gained popularity in the twenty-first century with the introduction of the decoupling index by the Organization of Economic Co-operation and Development (OECD, 2002). These decoupling indices are built on the foundations of the EKC hypothesis. According to the OECD (2002), decoupling occurs when the rate of environmental deterioration is less than the rate of economic growth. According to OECD, decoupling can be of two types, i.e., absolute decoupling or relative decoupling. When the environmental deterioration is declining or stable, it is called absolute decoupling. Contrary to this, relative decoupling refers to the situation when the growth rate of environmental deterioration is positive, and its rate of growth is lower than the growth rate of its driving force.

Tapio (2005) later developed a more comprehensive framework for analyzing decoupling that became the most widely used approach. The Tapio decoupling elasticity approach is constructed on the foundations of decoupling indices as proposed by OECD (2002); however, Tapio further disaggregated them into "strong" and "weak" decoupling. According to Tapio, strong decoupling means that economic growth can occur without any increase or with a decrease in environmental pressure. Contrary to this, weak decoupling implies that the environmental pressure still increases, but at a slower rate than economic growth. Mathematically, the Tapio decoupling elastic indicator is calculated using the following formula:

$$\text{Tapio decoupling elastic index } (ŋ) = \frac{\text{Percentage change in environmental pressure}}{\text{Percentage change in economic activity}}$$

The Tapio decoupling elastic index can be expansive, weak, recessive, or strong, and each scenario provides insights into the relationship between economic activity and environmental outcome. If ŋ = 1.0, it means that both environmental pressure and economic activity grow at the same rate. To avoid misinterpreting very small changes as evidence of decoupling in the analysis, a ±20% variation of the elasticity values around 1.0 is referred to as coupling. Therefore, the coupling is described as an elasticity value of 0.8 and 1.2. The growth of the variables can be negative or positive; therefore, the relationship between them is expressed as expansive coupling or recessive coupling. Eight logical possibilities of decoupling between carbon emissions and economic growth can be distinguished, as shown in Table 3 below.

Table 3: Classification of Coupling and Decoupling Relationship between Carbon Emissions and Economic Growth

Relationship between carbon emissions and economic growth	State of relationship	$\Delta C / C^{t-1}$	$\Delta G / G^{t-1}$	Value of ŋ
Expansive	Expansive negative decoupling	>0	>0	ŋ >1.2
	Expansive coupling	>0	>0	0.8 ≤ ŋ ≤1.2
Weak	Weak decoupling	>0	>0	0 ≤ ŋ ≤ 0.8
	Weak negative decoupling	<0	<0	0 ≤ ŋ ≤ 0.8
Recessive	Recessive coupling	<0	<0	0.8 ≤ ŋ ≤1.2
	Recessive decoupling	<0	<0	ŋ >1.2
Strong	Strong decoupling	<0	>0	ŋ <0
	Strong negative decoupling	>0	<0	ŋ <0

Source: *Adopted from Tapio's (2005) classification of decoupling states*

The decoupling index of energy-related carbon emissions and economic activity can be expressed mathematically as follows:

$$ŋ = \frac{\beta C}{\beta G}$$

Where

$$\beta C = C^t - C^o / C^0$$

and

$$\beta G = G^t - G^0 / G^0$$

$$ŋ = \frac{C^t - C^0/C^0}{G^t - G^0/G^0} \qquad \text{Eq. (2)}$$

In Eq. (2), ŋ is the decoupling index. C^0, G^0, C^t, and G^t represent the carbon emissions and GDP of the period (0) and (t), respectively. $\beta G = \frac{G^t - G^0}{G^0}$ and $\beta C = \frac{C^t - C^0}{C^0}$ stand for GDP growth rate and carbon emissions growth rate, respectively.

5. Results and Discussion

The complete time series LMDI-I decomposition analysis of carbon emissions in Pakistan is reported in Table 4. Similarly, graphical results of annual time series decomposition from LMDI-I are shown in Figure 1. The results reveal that energy intensity, fuel quality, affluence, renewable energy penetration, and population effect contributed positively towards carbon emissions' increase. Throughout the analysis, the population effect (ΔC_P) and affluence effect (ΔC_G) considerably contributed to carbon emissions, confirming the findings of Lin & Ahmad (2017) and Khan & Majeed (2019). During 1990-2019, population size has remained a significant component in rising carbon emissions, having a share of 12.92 million tonnes (Mtons).

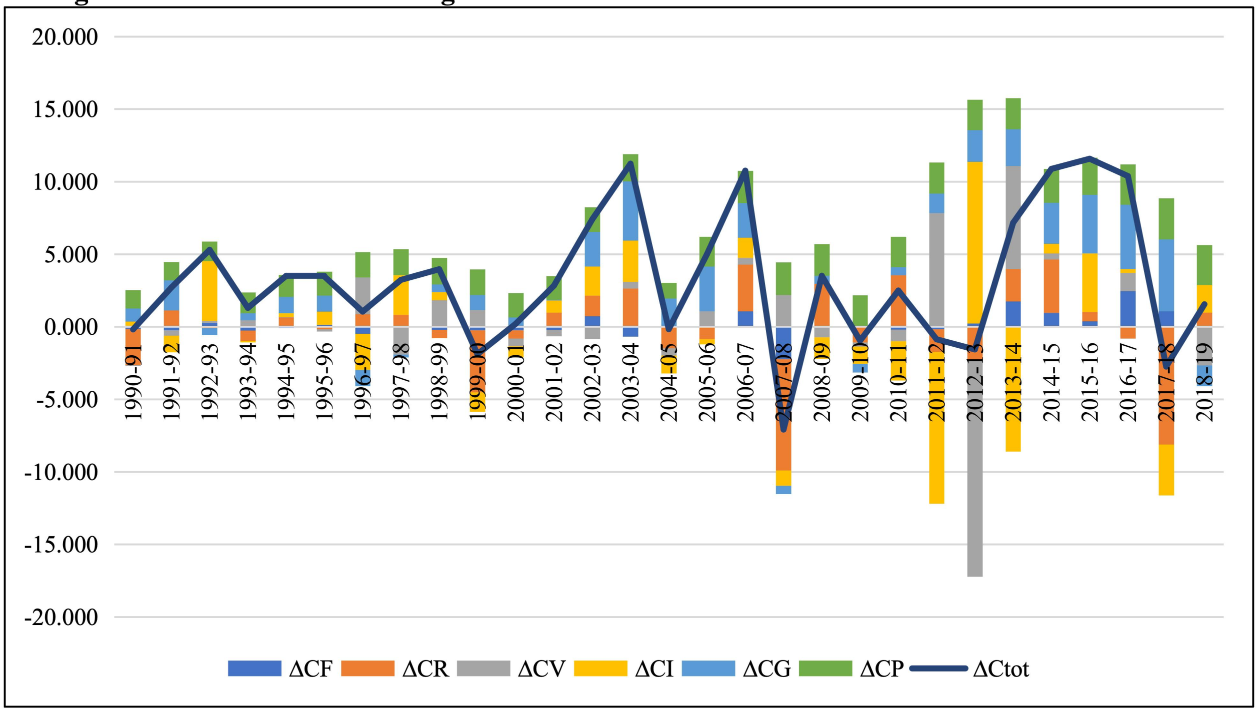
The population size effect accelerated Pakistan's increase in carbon emissions from energy use. Affluence increases 8.79 Mtons of carbon emissions. Though a declining trend has been observed in (ΔC_G) in few years, however it remained the dominant factor in increasing the carbon emissions. Fuel switching $\left(\Delta C_R\right)$ is a reason that declines emissions by -1.650 Mtons in 2019. The yearly contribution of energy intensity (ΔC_I) increased from 0.088 Mtons in 1990 to 0.195 Mtons in 2019. The renewable energy penetration impact (ΔC_V) contribution rate has increased to 0.6618 Mtons in 2019, indicating an increasing contribution of fossil fuels and a falling share of renewable energy in total energy consumption. In parallel with this, the impact of fuel quality $\left(\Delta C_F\right)$ also increased carbon emission to 0.288 Mtons. The fuel quality and energy intensity have a relatively minor impact among all contributing factors during the analysis period. Total carbon emissions due to fossil fuel consumption increased to 22.449 Mtons in the year 2019.

Table 4: Annual Time Series Log Mean Divisia Index-I Decomposition Results for Period 1990-2019

Years	ΔC_F	ΔC_R	ΔC_V	ΔC_I	ΔC_G	ΔC_P	ΔC_{tot}
1990-91	-0.0352	-0.5958	-0.0168	0.0877	0.2161	0.2991	-0.0450
1991-92	-0.0560	0.2692	-0.0912	-0.2728	0.4973	0.2991	0.6463
1992-93	0.0624	-0.0193	0.0363	0.9823	-0.1141	0.3213	1.2654
1993-94	-0.0591	-0.1734	0.1089	-0.0254	0.1043	0.3444	0.3090
1994-95	-0.0204	0.1564	0.0059	0.0628	0.2425	0.3651	0.8370
1995-96	0.0338	-0.0430	-0.0366	0.2160	0.2303	0.3949	0.8274
1996-97	-0.1122	0.2068	0.6073	-0.5994	-0.2289	0.4140	0.2482
1997-98	0.0017	0.1950	-0.4556	0.6537	-0.0416	0.4253	0.7709
1998-99	-0.0514	-0.1383	0.4367	0.1318	0.1080	0.4366	0.9466
1999-00	-0.0549	-1.0228	0.2770	-0.3212	0.1956	0.4246	-0.4529
2000-01	-0.0574	-0.1364	-0.1242	-0.1871	0.1246	0.3991	0.0478
2001-02	-0.0513	0.2343	-0.1069	0.1992	0.0079	0.3914	0.6767
2002-03	0.1744	0.3366	-0.2026	0.4836	0.4519	0.4067	1.7721
2003-04	-0.1616	0.6279	0.1143	0.6776	0.7377	0.4520	2.6878
2004-05	0.0135	-0.3496	-0.1210	-0.2952	0.5935	0.2584	-0.0780
2005-06	0.0081	-0.2065	0.2455	-0.0820	0.5202	0.4924	1.1982
2006-07	0.2535	0.7718	0.1075	0.3341	0.3908	0.5330	2.5720
2007-08	-0.5307	-1.8336	0.5240	-0.2550	-0.0888	0.5386	-1.6961
2008-09	-0.0163	0.7092	-0.1551	-0.3529	0.0877	0.5227	0.8387
2009-10	-0.0143	-0.2420	-0.0709	-0.2806	-0.0948	0.5206	-0.2304
2010-11	-0.0461	0.8516	-0.1884	-0.6512	0.0878	0.5012	0.6132
2011-12	-0.0426	-0.3747	1.8759	-2.4976	0.2088	0.5125	-0.2082
2012-13	0.0570	-0.5410	-3.5753	2.6598	0.3442	0.5009	-0.3749
2013-14	0.4160	0.5349	1.6971	-2.0543	0.4018	0.5116	1.7130

2014-15	0.2293	0.8822	0.0966	0.1618	0.4350	0.5552	2.6031
2015-16	0.0920	0.1537	-0.0172	0.9611	0.5951	0.6114	2.7669
2016-17	0.5870	-0.1927	0.3004	0.0611	0.6262	0.6629	2.4834
2017-18	0.2540	-1.9408	0.0022	-0.8340	0.6638	0.6752	-0.6583
2018-19	-0.0108	0.2362	-0.6273	0.4495	-0.1921	0.6621	0.3697
1990-2019	0.2883	-1.6503	0.6618	0.1951	8.7888	12.9242	22.4496

Figure 1: The Effects of Driving Factors of Carbon Emissions in Pakistan from 1990 to 2019



Source: *Author's own representation*

Table 5 displays the results of the Tapio decoupling indices analysis with the help of Eq. (2). Figure 2 depicts the graphical results of the decoupling indicator. The results reveal that the outlier values of the coupling index appear in the period of 2005–06, 2010–2011, and 2018–2019. These three points are found to be in the state of expansive coupling, as opposed to the other points, which are in the state of decoupling. When it comes to the decoupling elasticity, three points appear in the same weak decoupling state. Similarly, the strong decoupling state is represented by eight points, while fifteen points are in the expansive decoupling state. Furthermore, we discovered that the decoupling index values are largely distributed in the region that is greater than 1, representing that during the past three decades, as economic development has increased, so have fossil fuel-related carbon emissions in Pakistan.

Table 5: States of Coupling and Decoupling of Carbon Emissions and Economic Growth for 1990-2019

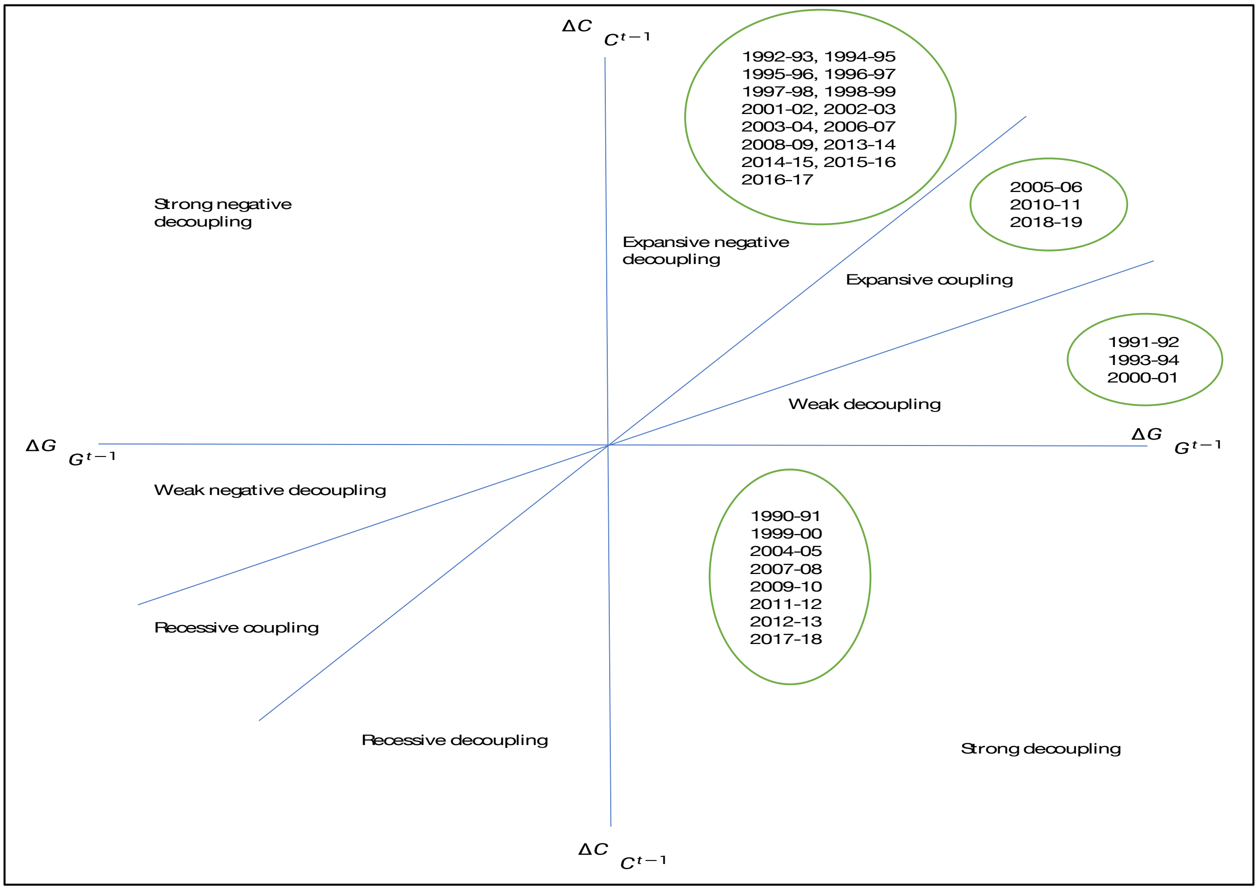
Years	β C	β G	Elasticity = β C / β G	Interpretation
1990-91	-0.0043	0.0506	-0.08	Strong decoupling
1991-92	0.0620	0.0771	0.80	Weak decoupling
1992-93	0.1144	0.0176	6.51	Expansive negative decoupling

1993-94	0.0251	0.0374	0.67	Weak decoupling
1994-95	0.0662	0.0496	1.33	Expansive negative decoupling
1995-96	0.0614	0.0485	1.27	Expansive negative decoupling
1996-97	0.0173	0.0101	1.71	Expansive negative decoupling
1997-98	0.0530	0.0255	2.08	Expansive negative decoupling
1998-99	0.0618	0.0366	1.69	Expansive negative decoupling
1999-00	-0.0278	0.0426	-0.65	Strong decoupling
2000-01	0.0030	0.0355	0.09	Weak decoupling
2001-02	0.0427	0.0251	1.70	Expansive negative decoupling
2002-03	0.1071	0.0578	1.85	Expansive negative decoupling
2003-04	0.1468	0.0755	1.94	Expansive negative decoupling
2004-05	-0.0037	0.0652	-0.06	Strong decoupling
2005-06	0.0573	0.0590	0.97	Expansive coupling
2006-07	0.1163	0.0483	2.41	Expansive negative decoupling
2007-08	-0.0687	0.0170	-4.04	Strong decoupling
2008-09	0.0365	0.0283	1.29	Expansive negative decoupling
2009-10	-0.0097	0.0161	-0.60	Strong decoupling
2010-11	0.0260	0.0275	0.95	Expansive coupling
2011-12	-0.0086	0.0351	-0.25	Strong decoupling
2012-13	-0.0156	0.0440	-0.36	Strong decoupling
2013-14	0.0725	0.0467	1.55	Expansive negative decoupling
2014-15	0.1027	0.0473	2.17	Expansive negative decoupling
2015-16	0.0990	0.0553	1.79	Expansive negative decoupling
2016-17	0.0808	0.0555	1.46	Expansive negative decoupling
2017-18	-0.0198	0.0584	-0.34	Strong decoupling
2018-19	0.0114	0.0099	1.15	Expansive coupling

The Tapio decoupling indicator results reveal that during the period of analysis, Pakistan had four decoupling states, namely strong decoupling, weak decoupling, expansive negative decoupling, and expansive coupling. Strong decoupling was observed in 1990-91, 1999-00, 2004-05, 2007-08, 2009-10, 2011-12, 2012-13, and 2017-18, demonstrating that while economic growth climbed, carbon emissions decreased. Furthermore, weak decoupling was reported in 1991-92, 1993-94, and 2000-01. Weak decoupling occurs when economic growth exceeds the growth of carbon emissions. Nevertheless, Pakistan has also experienced expansive negative decoupling during 1992-93, 1994-95, 1995-96, 1996-97, 1997-98, 1998-99, 2001-02, 2002-03, 2003-04, 2006-07, 2008-09, 2013-14, 2014-15, 2015-16 and 2016-2017, demonstrating that, during these years, the carbon emissions growth outpaced economic growth. This warns the government that it must diverge away from the energy systems that rely on fossil-fuel–based energy systems and toward renewable ones.

Moreover, Tapio's decoupling status shows that during 2005-06, 2010-11, and 2018-19, the country experienced expansive coupling. The state of expansive coupling illustrates that economic growth and carbon emissions were not uncoupled, implying that there was no indication of decoupling, and both rose in positive terms. The results of the Tapio elasticity analysis reveal the presence of expansive negative decoupling state in Pakistan for most of the period. In contrast, weak decoupling, strong decoupling, and expansive coupling have also been seen in different years. These results are comparable to those of Khan & Majeed (2019). The burning of extremely carbon-intensive fossil fuels in Pakistan has been attributed as a main contributor to the expansive negative decoupling state.

Figure 2: States of Decoupling and Coupling of Carbon Emissions and Economic Growth for 1990-2019



Source: Author's own representation

Hydropower was once a key component of the power sector of Pakistan, accounting for 45% of total power generation in 1991 (Asian Development Bank, 2016). Since 1992-93, the trend in the share of power generation between thermal and hydel has changed. The proportion of hydel is continuously falling while the percentage of thermal energy is constantly increasing. In 1998, hydel had a nearly 13.1% share, which had dropped to 7.7% in 2017-18. One of the primary causes of decreasing power generation from hydel power plants is the non-availability of water (Government of Pakistan, 2019). At the same time, the diminishing ratio of hydel indicates the shortsightedness of policies as well as the inability of governments to undertake such projects in a timely manner.

The consumption of petroleum products increased over the 1990s decade. It has increased by about 6% yearly. On the other hand, the amount of gas consumed grew by 2.7% annually. However, the consumption of coal, which showed wide variation in its annual consumption pattern, grew only by 0.9%. During this decade, the transport sector was the largest oil consumer, accounting for 47.7% of total consumption. It was mainly due to the growth in motorized vehicles at about 8% per annum. The transport sector's demand for petroleum increased at a 6.8% annual rate (Government of Pakistan, 2001).

Pakistan’s dependence on natural gas in its total energy mix is decreasing over time. In 2005, gas accounted for about half of Pakistan’s primary energy mix. In 2006, Pakistan's reliance on natural gas hit an all-time high of 50.4% of the total energy mix. Since then, due to the lack of major gas field expansion, the share of gas has steadily declined, and the proportion of imported energy demand started to increase. Between 1998-2001, Pakistan’s dependency on oil reached 43.5% (Government of Pakistan, 2019). Moreover, recently increased coal and imported LNG consumption since 2015 constituted a magnificent increase of the stated fuel in the energy mix. In 2017–18, the domestic supply of gas was nearly around 35% of the total primary energy supply, while oil was reported 31% of the total supply (Malik, Qasim & Saeed, 2019). Weak decoupling was recorded in 2000-01, which might be attributed to decreasing consumption of petroleum products as a result of the September 11, 2001, events.

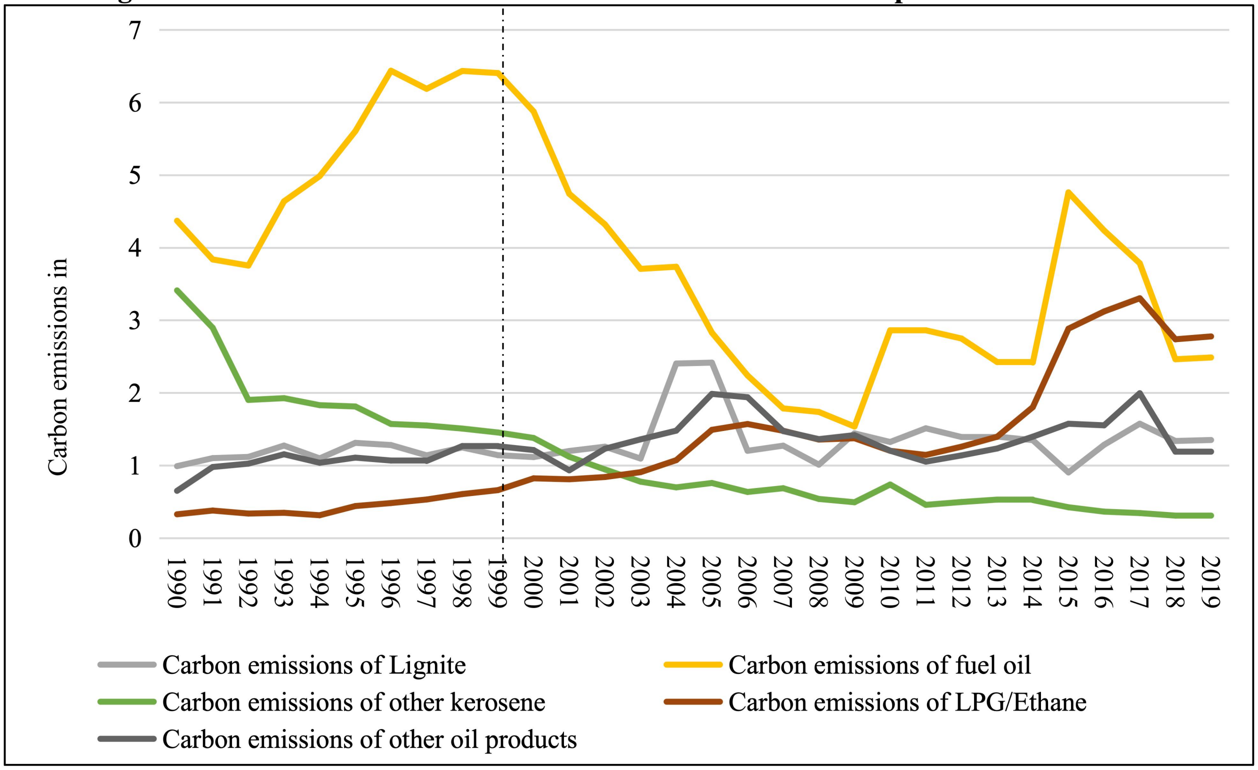
According to Mahmood & Shahab (2014), after 2001, coal consumption in the cement industry increased by 61%. The basic reason for the expansive negative decoupling is the transition of the energy use of the cement factories, i.e., from gasoline to coal, which has the highest carbon intensity. Carbon emissions showed strong decoupling in 2007-08. During this period, the country experienced a serious energy shortage, and the factories had to deal with frequent power interruptions, which restrained the manufacturing industry from working at its full production capacity. When the cost of generating thermal energy grew, WAPDA, due to its weak financial position, was unable to procure all of the electricity that private sector power projects could supply (Khawaja, Mahmood & Qadir, 2010).

During the first three years of the 2010s, high oil prices (above $100 per barrel) decreased demand for petroleum, resulting in fewer imports. During the same time period, a steady decline in coal prices induced local traders not to import a large quantity of coal, due to which the sectors were bound to move to informal sources of energy, like biofuels. The second reason for the apparent reduction in carbon emissions might be the shortage of energy in the beginning years of the study period, which reduced the operating rates of the energy-intensive industries (Malik et al., 2019).

The percentage of consumption of oil has decreased significantly since 2014. The proportion of the power sector in oil consumption fell substantially. The newly installed power plants shifted to inexpensive fuels, but the transport sector’s proportion of oil use grew. The rising share of transportation is primarily due to the lower petrol prices in the country and rising imports of automobiles. During July to February 2017–18 (a period of strong decoupling), the percentage of the transport sector share in oil consumption climbed to 64.40% from 57.20% over the course of the same months as of the previous year. However, with the advent of cheaper alternative energy sources such as LNG, hydel, and coal, the percentage of power fell to 26.40% from 33.20% during the periods under discussion (Malik et al., 2019).

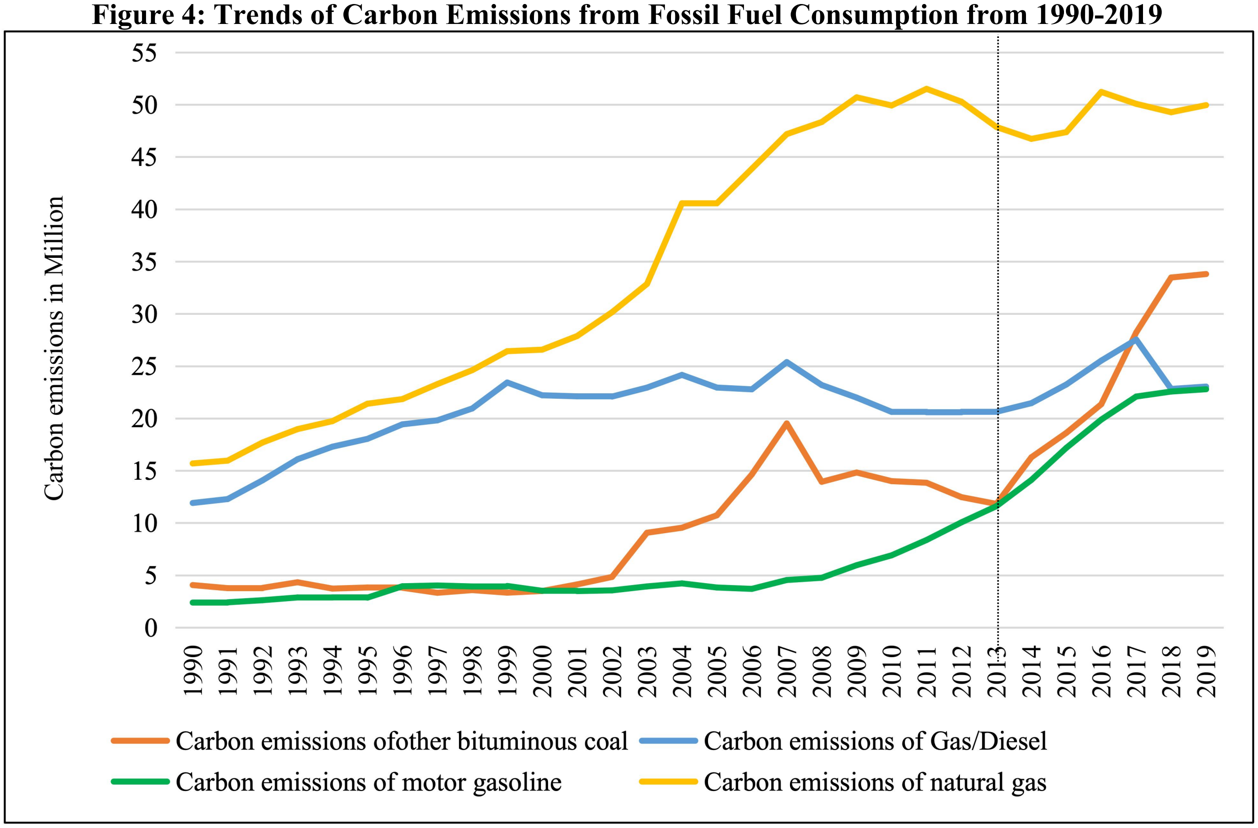
In recent years, Pakistan has embraced new sources of energy such as solar, wind, LNG, and bagasse-based power. Although additional sources of energy have been added, the scale of the addition of renewable energy remains minor. Similarly, the percentage share of coal stayed in the single digit throughout the previous two decades, except for 2018, where it has a recorded share of 12.7% in total energy consumption. Likewise, the share of renewables was 0.3% in 2015, which steadily increased to 1.1% in 2018. Nuclear, on the other hand, has also steadily increased to 2.7% in 2018 from 0.2% in 1997 (Government of Pakistan, 2019). Furthermore, in recent years construction sector has begun working on LNG-based power projects and imported coal, with the anticipation that such kinds of projects would boost the need for these imported fuels in the future. To summarize, as growth in the primary energy supply mostly comes from a rise in the fossil fuel supply, due to this reason, Pakistan’s carbon emissions are growing with time.

Figure 3: Trends of Carbon Emissions from Fossil Fuel Consumption from 1990-2019



Source: *Author's own representation*

Figure 4: Trends of Carbon Emissions from Fossil Fuel Consumption from 1990-2019



Source: *Author's own representation*

6. Conclusion

Determining the elements that cause carbon emissions are required to adopt effective mitigation programs. The driving forces of carbon emissions are investigated using Log Mean Divisa Index-1 decomposition techniques for Pakistan from 1990 to 2019. Fuel switching helps to reduce carbon emissions. Energy intensity, fuel quality, renewable energy penetration effect, economic activity, and population all contribute positively to increased carbon emissions, according to the breakdown results. The data reveal that across the research period, both population and prosperity played a substantial role in carbon emissions.

Pakistan's increase in carbon emissions from energy use was hastened by the population expansion effect. Tapio's decoupling status of fossil fuel related emissions from economic growth depicts that the country has gone through four decoupling states; however, the most notable state is expansive negative indicating that the growth in carbon emissions exceeds economic growth. Weak decoupling has also been noted in many years, which implies that economic growth has been relatively higher than carbon emission growth. This highlights the need for the following policy actions to sustain long-term economic development.

1. The burning of fossil fuel for energy generation is the primary source of carbon emissions. Therefore, replacing polluting coal, gas and oil-based power plants with renewable sources would reduce emissions. Renewable energy investment requires identifying qualifying climate change investment projects.
2. If the economy becomes more energy efficient and uses cleaner sources for energy mix, the country’s economic growth and carbon emissions can be decoupled. As the GDP growth rate is low and carbon emissions are high, the country should pursue concessional international climate finance from environmental organizations such as green bonds, blue bonds, and brown bonds to invest in green technologies.
3. The Government of Pakistan has planned to reduce 50% of its GHG emissions of 2016 baseline projected levels by 2030. In this regard, improving the overall investment climate is important through national capital restoration initiatives, e.g., the Ten Billion Tree Tsunami Program and promoting Marine Protected Area. Similarly, a substantial increase in international funding and sponsorship from the nations that are parties to the UNFCCC, Kyoto Protocol, and Paris Agreement would be required.
4. The country must develop measures to lessen the population's carbon footprint. The use of goods and services, transportation, and household energy all contribute to an individual's carbon footprint. Therefore, lifestyle changes would help reduce carbon footprint. In this regard, it is crucial to take action to offset individuals' unavoidable carbon footprints via carbon offsets, making them effectively carbon neutral in their daily lives.
5. The rate of urbanization rises with the rise in population size. Energy is required for urban infrastructure and life, increasing carbon emissions. As a result, a reduction in the rate of urbanization may be a contributory policy to reduce carbon emissions.

The current study investigates the factors contributing to carbon emissions in Pakistan. The results found that the major drivers of carbon emissions in Pakistan are population and economic growth. On the other hand, political and social factors can also affect environmental impacts, such as policy decisions, cultural norms, and consumer behaviour. These factors can have a significant impact on the adoption of clean technologies and the reduction of GHGs. Therefore, for the future research, social and political factors can be investigated in order to get robust policy insights for reducing carbon emissions.

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Availability of Data and Materials: Data is self-collected from secondary sources.

References

Abbas, M. N., & Andlib, Z. (2026). Digitalization, Climate Change, and Labor Force Participation: Empirical Evidence and Policy Perspectives. Pakistan Journal of Economic Studies (PJES), 9(1), 40-50.

Aden, N. (2016). The Roads to Decoupling: 21 Countries Are Reducing Carbon Emissions While Growing GDP. *World Resources Institute*. https://www.wri.org/insights/roads-decoupling-21-countries-are-reducing-carbon-emissions-while-growing-gdp

Ahmad, W., Majeed, T., & Andlib, Z. (2020). Tourism Led Growth Hypothesis: Empirical Evidence from Five South Asian Countries. *Bulletin of Business and Economics (BBE)*, *9*(1), 51–59.

Andlib, Z., Scicchitano, S., & Padda, I. U. H. (2024). The role of natural resources, fintech, political stability, and social globalization in environmental sustainability: Evidence from the United Kingdom. *Resources Policy*, *91*, 104922.

Ang, B. W., Liu, F. L., & Chung, H.-S. (2004). A generalized Fisher index approach to energy decomposition analysis. *Energy Economics*, *26*(5), 757–763. https://doi.org/10.1016/j.eneco.2004.02.002

Anser, M. K., Yousaf, Z., Usman, B., Nassani, A. A., Qazi Abro, M. M., & Zaman, K. (2020). Management of water, energy, and food resources: Go for green policies. *Journal of Cleaner Production*, *251*, 119662. https://doi.org/10.1016/j.jclepro.2019.119662

Asghar, M. M., Wang, Z., Wang, B., & Zaidi, S. A. H. (2020). Nonrenewable energy-environmental and health effects on human capital: Empirical evidence from Pakistan. *Environmental Science and Pollution Research International*, *27*(3), 2630–2646. https://doi.org/10.1007/s11356-019-06686-7

Asian Development Bank. (2016). *Using Water as Fuel: Pakistan's Ranolia Hydropower Project*. Asian Development Bank. (Pakistan). https://www.adb.org/results/using-water-fuel-pakistan-s-ranolia-hydropower-project

Aslam, H., Nazir, A., & Zia, U. ur R. (2021). *Pakistan's Way Forward towards a Green Economy: Perspectives for a Clean Energy Transition*. Sustainable Development Policy Institute.

Attari, M. I. J., Hussain, M., & Javid, A. Y. (2016). Carbon emissions and industrial growth: An ARDL analysis for Pakistan. *International Journal of Energy Sector Management*, *10*(4), 642–658. https://doi.org/10.1108/IJESM-04-2014-0002

Awan, A. G., & Yaseen, G. (2017). Global Climate Change and Its Impact on Agriculture Sector in Pakistan. *American Journal of Trade and Policy*, *4*(3), Article 3. https://doi.org/10.18034/ajtp.v4i3.425

Bakhsh, K., Latif, A., Ali, R., & Yasin, M. A. (2021). Relationship between adaptation to climate change and provincial government expenditure in Pakistan. *Environmental Science and Pollution Research*, *28*(7), 8384–8391. https://doi.org/10.1007/s11356-020-11182-4

Beyene, S. D. (2022). Human activities and environmental quality: Evidence beyond the conventional EKC hypothesis. *Heliyon*, *8*(9), e10756. https://doi.org/10.1016/j.heliyon.2022.e10756

Butt, D., Myllyvirta, L., & Dahiya, S. (2021). *CO2 Emissions from Pakistan's Energy Sector*. Centre for Research on Energy and Clean Air (CREA). https://energyandcleanair.org/publication/co2-emissions-from-pakistans-energy-sector/

Climate Transparency. (2020). *Pakistan's Climate Action and Responses to the Covid-19 Crisis*. https://www.climate-transparency.org/wp-content/uploads/2021/11/Pakistan-CP-2020.pdf

Correia, M. (2019). Sustainability: An Overview of the Triple Bottom Line and Sustainability Implementation. *International Journal of Strategic Engineering*, *2*, 29–38. https://doi.org/10.4018/IJoSE.2019010103

Eckstein, D., Künzel, V., & Schäfer, L. (2021). *Global Climate Risk Index 2021*. Germanwatch e.V. https://www.germanwatch.org/en/19777

Elkington, J. (1997). *Cannibals with forks: The triple bottom line of 21st century business*. Capstone Pub.

Farsi, M., Hosseinian-Far, A., Daneshkhah, A., & Sedighi, T. (2017). *Mathematical and Computational Modelling Frameworks for Integrated Sustainability Assessment (ISA)* (A. Hosseinian-Far, M. Ramachandran, & D. Sarwar, Eds.). Springer. http://oro.open.ac.uk/49947/

Government of Pakistan. (2001). *Economic Survey of Pakistan, 2000-01*. Finance Division, Islamabad. http://111.68.102.42:8080/xmlui/bitstream/handle/123456789/6548/Economic%20Survey%2020 00-2001.PDF?sequence=1&isAllowed=y

Government of Pakistan. (2008). *Economic Survey of Pakistan, 2007-08*. Finance Division, Islamabad. http://111.68.102.42:8080/xmlui/bitstream/handle/123456789/6555/Pakistan%20Economic%20S urvey%202007-2008.PDF?sequence=1&isAllowed=y

Government of Pakistan. (2019). *Economic Survey of Pakistan, 2018-19*. Finance Division, Islamabad. https://www.finance.gov.pk/survey/chapters_19/Economic_Survey_2018_19.pdf

Jabeen, A., & Khan, S. A. (2022). Economic growth, social inclusion, and environmental protection: Assessing the existence of green growth in Pakistan. *Environmental Science and Pollution Research*, *29*(44), 66675–66688. https://doi.org/10.1007/s11356-022-20467-9

Kaya, Y. (1990). *Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios.* Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, (mimeo).

Khan, S., & Majeed, M. T. (2019). Decomposition and Decoupling Analysis of Carbon Emissions from Economic Growth: A Case Study of Pakistan. *Pakistan Journal of Commerce and Social Sciences (ISSN 1997-8553)*, *13*(4), 868–891.

Khan, S., & Majeed, M. T. (2023). Toward economic growth without emissions growth: The role of urbanization & industrialization in Pakistan. *Journal of Environmental Studies and Sciences*, *13*(1), 43–58. https://doi.org/10.1007/s13412-022-00797-3

Khawaja, I., Mahmood, T., & Qadir, U. (2010). Social Impact of Global Recession on Pakistan. *Pakistan Economic and Social Review*, *48*(2), 261–278.

Kono, N. (2014). Brundtland Commission (World Commission on Environment and Development). In A. C. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 450–452). Springer Netherlands. https://doi.org/10.1007/978-94-007-0753-5_441

Lin, B., & Ahmad, I. (2017). Analysis of energy related carbon dioxide emission and reduction potential in Pakistan. *Journal of Cleaner Production*, *143*, 278–287. https://doi.org/10.1016/j.jclepro.2016.12.113

Mahmood, M. T., & Shahab, S. (2014). Energy, Emissions and the Economy: Empirical Analysis from Pakistan. *Pakistan Development Review*, *53*, 383–400. https://doi.org/10.30541/v53i4IIpp.383-401

Malik, S. M., Awan, H., & Khan, N. (2012). Mapping vulnerability to climate change and its repercussions on human health in Pakistan. *Globalization and Health*, *8*(1), 31. https://doi.org/10.1186/1744-8603-8-31

Malik, S., Qasim, M., & Saeed, H. (2019). *Energy Security in Pakistan: A Quantitative Approach to a Sustainable Energy Policy* (Number 1024). Asian Development Bank. (Pakistan). https://www.adb.org/publications/energy-security-pakistan-sustainable-energy-policy

Mustafa, Z. (2011). Climate Change amd its Impact with Special Focus in Pakistan. Symposium on "Changing Environmental Pattern and its impact with Special Focus on Pakistan."

National Transmission and Dispatch Company (NTDC). (2019). *Indicative Generation Capacity Expansion Plan 2018-40*. Power Sector Planning. https://nepra.org.pk/Admission%20Notices/2019/09-September/IGCEP%20Plan%20(2018-40).pdf

OECD. (2002). *Decoupling: A Conceptual Overview* (Paper No. 10). OECD Publishing. https://www.iatp.org/sites/default/files/Decoupling__A_Conceptual_Overview.htm

Rahman, H. U., Ali, G., Zaman, U., & Pugnetti, C. (2021). Role of ICT Investment and Diffusion in the Economic Growth: A Threshold Approach for the Empirical Evidence from Pakistan. *International Journal of Financial Studies*, *9*(1), Article 1. https://doi.org/10.3390/ijfs9010014

Rasheed, R., Tahir, F., Afzaal, M., & Ahmad, S. R. (2022). Decomposition analytics of carbon emissions by cement manufacturing – a way forward towards carbon neutrality in a developing country. *Environmental Science and Pollution Research International*, *29*(32), 49429–49438. https://doi.org/10.1007/s11356-022-20797-8

Raza, M. Y., Chen, Y., & Tang, S. (2022). Assessing the Green R&D Investment and Patent Generation in Pakistan towards CO2 Emissions Reduction with a Novel Decomposition Framework. *Sustainability*, *14*(11), 6435. https://doi.org/10.3390/su14116435

Ritchie, H., Roser, M., & Rosado, P. (2020). *CO_2 and Greenhouse Gas Emissions*. Our World in Data. https://ourworldindata.org/co2-emissions

Shahid, Z., & Piracha, A. (2016). Awareness of Climate Change Impacts and Adaptation at Local Level in Punjab, Pakistan. In B. Maheshwari, B. Thoradeniya, & V. P. Singh (Eds.), *Balanced Urban Development: Options and Strategies for Liveable Cities* (pp. 409–428). Springer International Publishing. https://doi.org/10.1007/978-3-319-28112-4_25

Syed, A., Raza, T., Bhatti, T. T., & Eash, N. S. (2022). Climate Impacts on the agricultural sector of Pakistan: Risks and solutions. *Environmental Challenges*, *6*, 100433. https://doi.org/10.1016/j.envc.2021.100433

Syed, A.-R., & Bukhari, A. (2019). *Starting-up-unlocking-entrepreneurship-in-pakistan*. McKinsey & Company. https://www.mckinsey.com/~/media/mckinsey/featured%20insights/middle%20east%20and%20africa/pakistans%20start%20up%20landscape%20three%20ways%20to%20energize%20entrepreneurship/starting-up-unlocking-entrepreneurship-in-pakistan.ashx

Tapio, P. (2005). Towards a theory of decoupling: Degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transport Policy*, *12*(2), 137–151. https://doi.org/10.1016/j.tranpol.2005.01.001

United Nations. (1972). *Report of the United Nations Conference on the Human Environment*. https://wedocs.unep.org/xmlui/handle/20.500.11822/30829

Wyns, A. (2022). Disaster diplomacy in the wake of the 2022 Pakistan floods. *The Lancet Planetary Health*, *6*(11), e855–e856. https://doi.org/10.1016/S2542-5196(22)00240-6

Xiuhui, J., & Raza, M. Y. (2022). Delving into Pakistan's industrial economy and carbon mitigation: An effort toward sustainable development goals. *Energy Strategy Reviews*, *41*, 100839. https://doi.org/10.1016/j.esr.2022.100839