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Effects of trade liberalization on the global decoupling and decomposition of CO_2 emissions from economic growth

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A R T I C L E I N F O

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A B S T R A C T

Evidence of climate change is widespread and severe across all parts of the world. This poses a threat to humanity, and the entire environment. Appropriate policies are therefore required to help reduce greenhouse gas emission levels, limit the rate of global warming and its impact on climate change while pursuing national growth targets. This study employs the Tapio decoupling method to analyse the decoupling relationship (DR) between economic growth and carbon dioxide (CO_2) emissions from 1998 to 2018. We also apply the Logarithmic Mean Divisia Index (LMDI) decomposition method on an extended Kaya identity to analyse CO_2 emissions drivers in 145 countries. Last, the study examined the relative impacts of trade intensity and trade efficiency on the DR between economic growth and CO_2 emissions. The results revealed that regions with relatively many developing and emerging countries (i.e., SSA, EAP, LAC, MENA, and SA) generally performed Weak Decoupling (WD), Expansive Negative Decoupling (END) and Expansive Coupling (EC), and the decoupling process was largely unstable. The ECA and NA regions on the other hand, which are typically composed of developed economies performed stable WD and Strong Decoupling (SD) statuses throughout the study period. The evidence further revealed that while trade intensity, activity, population, output per carbon emission and Carbon Intensity (CI) effects promote CO_2 emissions, trade efficiency and energy intensity (EI) hinder emissions. We recommend that developing countries should enforce laws and cooperate with the developed economies to gain access to green technology to promote environmental sustainability.

1. Introduction

Over the years the world has seen an increased volume and value of trade among countries. Trade has been incredibly important for global economic progress. Global trade as a share GDP rose from 37.91 % in 1990 to 56.33 % in 2019 [1]. The World Trade Organization (WTO) projects that global commercial trade would further expand by 3.5 % by the end of 2022, slowing down sharply to 1 % by end of year 2023. According to international economic data, the top three exporting areas in 2022 were the Middle East (14.6 %), Africa (6.0 %), and North America (3.4 %). This is followed by Asia (2.9 %), Europe (1.8 %), and South America (1.6 %). In terms of import volume growth in 2022, statistics suggest that the Middle East (11.1 %) North America (8.5 %), and Africa (7.2 %) are the regions with the highest growth. Theoretically, trade is seen as a vehicle through which economies can grow and achieve economic

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prosperity. In view of this, several countries have applied different trade policies to liberalize their markets to encourage domestic and international trade. Through the spread of information and technology, trade liberalization increases productivity, opens up job opportunities for indigenes, encourages foreign direct investment (FDI), and improves resource-use efficiency.

Despite its benefits, trade does have adverse effects on the environment that must be taken into account. The Pollution Haven Hypothesis (PHH) argues that trade worsens the environmental conditions for host countries where the quality of institutions is low and regulatory frameworks are weakly implemented. Again, the scale effect hypothesis argues that the increase in highly sophisticated equipment for production increases energy consumption and worsens environmental quality [2,3]. According to the Environmental Kuznets Curve (EKC) hypothesis, pollution is an increasing function of economic growth; particularly when economic development is at its early phase [4,5]. Data also supports a co-movement between economic growth and CO_2 emissions (see Fig. 1).

According to Ref. [6], global CO_2 emissions continue to be on the rise. Global emissions increased from 20,511.1 Mt of CO_2 in 1990 to about 33,621.5 Mt of CO_2 in 2019, indicating an increase in emission levels by about 63.92 % [6]. The regional averages for Africa and Asia Pacific in 1990 were 526.2 Mt of CO_2 and 4893.8 Mt of CO_2, respectively, but increased to 1262.9 Mt of CO_2 for Africa and 16, 530.4 Mt of CO_2 for the Asian Pacific regions in 2019. The regional average of CO_2 emissions for Europe, however, declined from 5175.2 Mt of CO_2 in 1990 to 3816.8 Mt of CO_2 as of 2019, even though it remained significantly higher than most regions. The implication of the upward trend in emission levels is dire for global warming and climate change. According to Ref. [7], some of the disastrous effects of increased CO_2 emissions include high temperatures in some regions of the world, acidic rain, drought, rising sea levels, species loss and extinction, severe human health concerns, and food security.

This paper delves into the intricate interplay between trade, economic growth, and environmental sustainability. It seeks to explore the extent to which countries are succeeding in disentangling economic growth from CO_2 emissions, a critical issue in the context of worsening global warming and its associated dire consequences, as elucidated by the Intergovernmental Panel on Climate Change [7]. The literature is replete with studies exploring the nature of decouplingacross different countries and regions. For example, Ref [8] employed the Tapio Decoupling (TD) method to examine the DR between CO_2 emissions and the growth of the tourism industry in China. The estimated results showed that the DR alternated between negative decoupling and WD, implying that the Chinese tourism industry grew with less ecological footprint. Ref [9] analysed the DR between CO_2 emission and the transport sector in Pakistan, and found EC for the entire period though WD was observed in sub-samples. Ref [10] investigated the DR between CI from the manufacturing building sector and economic development in China. The WD and SD states were observed at different periods at the national level while four different decoupling stages alternated at the provincial level. Similarly, Ref [11] compared the decoupling trends in Japan and China using the OECD decoupling indicator on a data sample from 1992 to 2014 and found that while Japan achieved absolute decoupling, China achieved relative decoupling of economic growth from air-pollutant emissions. Additionally, Ref [12] found that larger proportions of the countries in higher-income countries have decoupled CO_2 emissions from economic growth.

The paper makes several noteworthy contributions to the existing body of literature. While previous studies have attempted to clarify whether output growth, either national or sectoral, has been decoupled from CO_2 emissions and the nature of such decoupling states in selected countries, an important question that the extant studies ignore to critically investigate are the main sources driving the trend of CO_2 emissions in the selected countries. A crucial policy question that follows from any decoupling analysis, is what explains the decoupling states identified. To answer this question, it is necessary to decompose the DR between CO_2 emission trends and economic growth, identify the primary sources, and analyse the interactions between these sources in order to understand the different types of decoupling states that are experienced. However, empirical studies combining decomposition analysis with

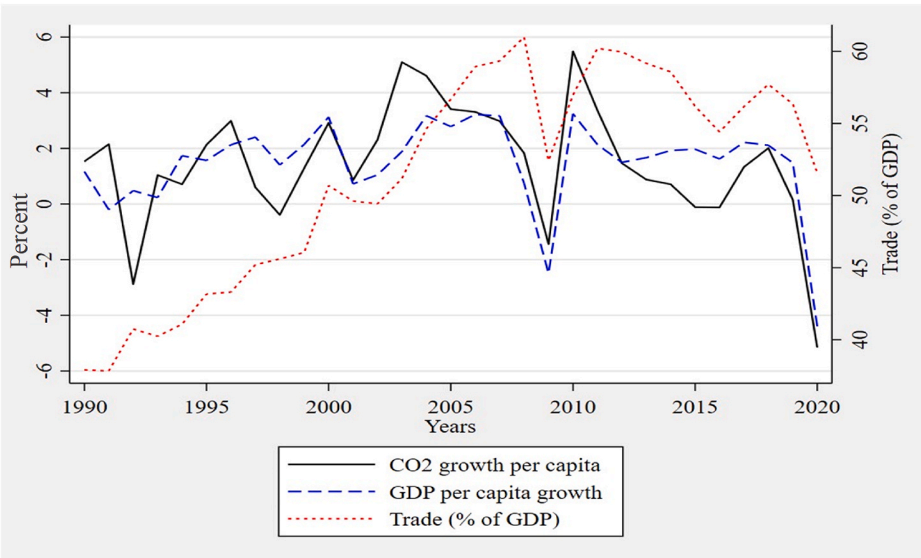

Fig. 1. Global trends in CO_2 emissions per capita growth, GDP per capita growth, and trade from 1990 to 2020.

decoupling techniques in an attempted to provide an in-depth scholarship of the extent, nature and facilitating conditions of the level and nature of DR between economic growth and CO_2 emissions across the globe is limited in the literature. The few existing empirical studies have however identified CI, economic output [13]; technical progress, industrial structure [13]; energy intensity [14]; affluence [15]; urbanization, industrialization and research and development [16] as key factors having a greater impact on decoupling process between economic growth and emissions. The role of trade liberalization in the DR economic growth and CO_2 emissions is highly unexplored in the literature. Ref [17] attempted to address this research gap by examining the direct impact of trade openness on CO_2 emissions, and then casually link the estimated dynamic relationship between trade openness and CO_2 emissions to explain its potential contribution in the decoupling process in 182 countries. This approach still leaves several doubts since the direct impact of trade in the decoupling mechanism is still not clear.

This current paper addresses this research gap and attempts to make the following modest contributions to the literature. First, it explores the contribution of trade liberalization in the DR between CO_2 emissions and economic growth. To do this, the study employs the TD method to examine the decoupling status of 145 countries from 1998 to 2018; and then integrates the Logarithmic Mean Divisia Index (LMDI) decomposition model into the TD model to examine the drivers of the decoupling process; with particular emphasis on trade liberalization. It is expected that this will provide richer information to guide policymakers' understanding of the ecological footprint of national output growth and trade activities. Second, the study attempts to conduct regional analysis of the state of decoupling and the drivers of decoupling mechanism of the selected regional blocs. Additionally, our analysis attempts to unearth the potential heterogeneities and commonalities within and between regional blocs about the dynamics of trade and its prominent role in the CO_2 emissions and economic growth decoupling. This study concentrates on key indexes that explain trade liberalization: trade intensity effect and trade quality (efficiency) effect. While trade intensity measures the depth of trade liberalization in a country, the quality of trade explains its effect on total emissions induced as a result of trade. This helps differentiate the volume (quantity) of trade to its quality in terms of its impact on the environment.

The rest of this paper is organized as follows. Section 2 reviews relevant theories and empirical literature. In section 3, the study explains the method used for the analysis and the nature of the data employed. Section 4 discusses the decoupling and decomposition results while section 5 concludes the study and provides policy recommendations based on the results obtained.

2. Literature review

2.1. Theoretical review

The EKC hypothesis first proposed by Kuznets [18] and later developed by Grossman and Krueger [19] is adopted for the analysis presented in this study. The theory suggest that the early stages of economic development engender high resource use and environmental pollution. However, after an economy attains certain level of economic advancement, further increases in growth reduces resource use and environmental pressure. Economies at such developed statuses value the quality of the environment just as they do economic growth. This implies development first gets dirty before becoming clean.

In a similar narrative, the PHH asserts that due to the lack of/or failure to implement environmental laws by some countries especially the developing ones, they become a safe haven for multinational companies to outsource their carbon-polluting plants to such jurisdictions. This increases emissions in the host country, even though the final products will most likely be consumed externally. The Pollution Halo (PHL) hypothesis on the other hand argues that such FDI inflows facilitate the inflow of energy-saving and pollution-abatement technologies, reduce carbon emissions and ensure environmental sustainability. The scale effect hypothesis on the other hand argues that even though such inflows of multinational companies into the domestic economy increase domestic industrial sector output, they heavily consume energy leading to an increase in emission levels. The validity or otherwise of these theories have been empirically verified in different setting. Studies such as [20,21] confirm the presence of the PHL hypothesis, while others [3,22] supports the presence of the PHH hypothesis.

2.2. Empirical review

The DR between economic growth and CO_2 emissions have been analysed for several countries and regions. Different strands of decoupling analyses are identified including those that focus on specific country-level analysis in China [10,23]; Cameroon [24]; Pakistan [9]; and Ghana [25]. Ref [23] compared the DR between CO_2 emissions and economic growth of the five major sectors of the Chinese economy (i.e., transport, agriculture, industrial, service and construction sectors) from 1992 to 2012. Adopting the TD method, the study observed that the WD state was mostly experienced throughout the study period. Ref [10] investigates the DR between CI from the manufacturing building sector and economic development in China's service sector. The WD and SD states were observed at different periods at the national level while four different decoupling stages alternated at the provincial level. Similarly, Ref [9] analysed the transport sector decoupling analysis from CO_2 emissions in Pakistan, and finds EC for the entire period though WD was observed in sub-samples. Ref [25] examines the DR between Ghana's economic growth and CO_2 emissions using the Tapio elasticity method from 1990 to 2018. The study finds the WD status dominated throughout the study period, even though SD and the Strong Negative Decoupling (SND) were observed in some periods. A number of these country specific studies have also compared the decoupling performance in a given city or group of cities. An observation of the country-specific studies is that the analysis is mostly focused on China or in developed countries [26–30]. Relatively little knowledge is known on such relationship in other regions and countries.

Another strand of decoupling studies is the cross-country level analysis. Ref [31] finds that while China mainly experienced EC and

WD states, the United States mostly experienced the WD and SD. Ref [32] also compared China and India and finds that China performed WD throughout the study period (1980–2014) while there was no regular decoupling state in India. In a related study, Ref [11] examined the decoupling trends in Japan and China using the OECD decoupling indicator on a data sample from 1992 to 2014. The study finds that while Japan achieved absolute decoupling, China achieved relative decoupling of economic growth from air-pollutant emissions. Ref [17] examined the impact of trade on the decoupling economic growth from CO_2 emissions in 182 countries. The TD model revealed that while the decoupling performance converge on WD, heterogeneous decoupling results were observed for the different countries based on the income level differences. The high-income economies performed the best decoupling status. This was followed by upper-middle income countries and low-income countries. Countries in the low-income category were observed to have performed the worst decoupling status.

In terms of regional decoupling comparison, Ref [15] employed the TD model to investigate the global and regional decoupling trends and examined the contributions of affluence, CI, EI, and population on the decoupling process from 2000 to 2014. The study concluded that developed countries performed better decoupling of stable WD and switches to the SD status. There was, however, no clear decoupling state in the developing countries. Further, Ref [12] disaggregated CO_2 emissions into total CO_2 emissions, CI, and CO_2 per capita and analysed the DR with economic growth. The findings show that economic growth decoupled from all measures of CO_2 emissions in a sequential order. Specifically, about 74 % of the sampled countries have decoupled economic growth from CI, while 35 % and 21 % decoupled growth from CO_2 per capita and total CO_2 emissions respectively.

3. Data and methods

3.1. Data

The analysis presented in the current study focuses on 145 countries spanning the period 1998 to 2018. The study compares the decoupling and decomposition results for both national and regional levels (divided into Latin America and the Caribbean, sub-Saharan Africa, Middle East and North Africa, North America, East Asia and the Pacific, South Asia, and Europe and Central Asia). The included regions and the list of countries are presented in the appendix section of this study. The number of countries used is highly representative given that it includes many countries that constitute about 94.24 % of global CO_2 emissions according to data from Our World in Data [33]. The main reason for excluding some countries was due to data unavailability on key variables used for the analysis in the present study. The Energy Information Administration [34] and the World Bank's World Development indicators [1] databases serve as the primary sources of the data used for the analysis. The summary of variables used are presented in Table 1.

Regarding the measurement of the variables, the study employed total CO_2 emissions measure in kiloton. The GDP of a country measure at constant 2015US$ was used to correct for the effect of inflation and to enable international comparison of the values. The World Bank defines trade liberalization as the sum of an economy's export and imports divided by GDP, while population measure the total number of people residing in a country at a given period. Total energy consumption is measured in million metric tons of oil equivalence and represents the amount of energy used by all economic sectors in a given year. The descriptive summary of all the variables shows that there exists some level of heterogeneity among the sampled countries. This is however, expected as some countries are large in population and land size, and therefore will have large economic output than relatively smaller ones. Institutional and structural differences may also have accounted for such differences.

3.2. The Tapio decoupling (TD) model

Several decoupling methods have been used to conduct decoupling analysis. However, the two widely used decoupling methods are the OECD decoupling factor model and the Tapio elasticity method developed by Tapio in 2005 [35]. The present study adopts the Tapio method given its qualities over the OECD decoupling model. The OECD method is sensitive to the choice of a base year, thereby affecting the stability of the results. Again, according to Ref. [12], the OECD method is able to yield efficient results only when there is a reduction in emission intensities. However, expansion in an economy may be associated with a fall in the growth of emissions. Similarly, a country may experience a concurrent decline in economic growth and an increase in emission levels. To adequately solve these limitations of the OECD method, the TD method provides eight sets of decoupling statuses (see Fig. 2) which is able to handle any of such scenarios. The TD analysis computes an elasticity indicator of the ratio between the growth of CO_2 emissions, and growth of the economy. The advantages of this decoupling technique are its less data requirement, less sensitive to base year choice, and its simplicity in construction and comprehension. The TD indicator is specified in equation (1),

Table 1
Summary of variables.

VARIABLE		*Mean*	*Std. Dev.*	*Unit*	*Source*
CO_2	CO_2 missions	193036.2	788763.6	Kiloton	WB
GDP	Gross Domestic product	4.17E+11	1.57E+12	Constant 2015 US$	WB
Pop	Population	4.40E+07	1.51E+08	Total population	WD
E	Energy consumption	83.10708	306.6539	MMTOE	EIA
Trade	International trade	84.05099	49.22535	Exports + Imports	WB

Note: 'WB' and 'EIA' refer to World Bank and Energy Information Administration.

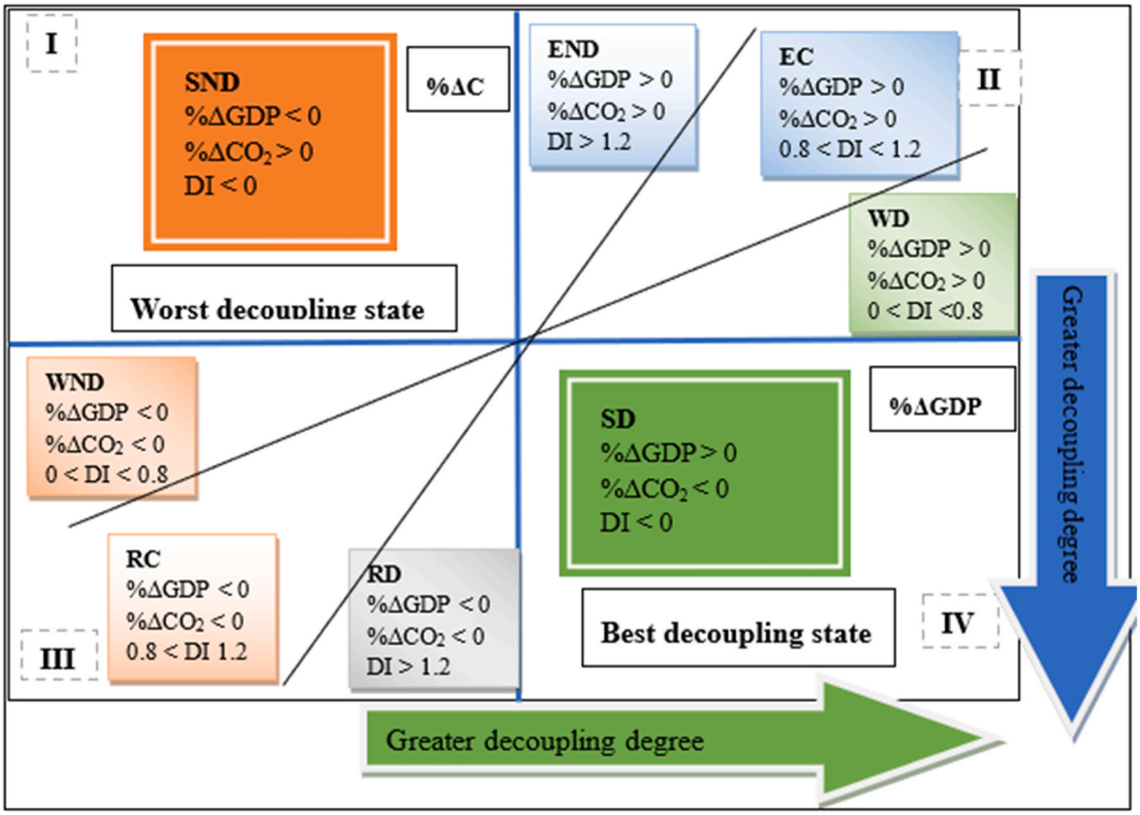

Fig. 2. The Tapio decoupling statuses.

$$DI = \frac{\Delta CO_2 / CO_2^{\,0}}{\Delta GDP / GDP^0} = \frac{\left(CO2^t - CO2^0\right)/CO_2^{\,0}}{\left(GDP^t - GDP^0\right)/GDP^0} = \frac{\%\Delta CO_2}{\%\Delta GDP} \tag{1}$$

where DI represents the decoupling elastic indicator, $\Delta CO2$ and ΔGDP represent the changes in CO_2 emissions and GDP respectively from the base year ***0*** to the target year ***t***. to conclude on the decoupling state in a given period, the ***DI*** is compared with the growth rates in CO_2 emissions and GDP growth as shown in Fig. 1. Given positive GDP growth values (i.e. $\%\Delta GDP > 0$), smaller values of ***DI*** indicate a stronger decoupling effect, and this implies that the dependence relationship between economic growth and CO_2 emission is receding [12]. On the contrary, negative GDP growth (i.e. $\%\Delta GDP < 0$) values coupled with smaller ***DI*** value indicates strong dependence of economic growth on carbon emission. Thisis the worse decoupling status that any carbon-free conscious government would want to discourage. The ideal decoupling status is the SD state, indicating improvement in environmental sustainability and a movement towards low-carbon economy where economic growth value is increasing ($\%\Delta GDP > 0$) while the growth in carbon emissions is decreasing **($\%\Delta CO_2 < 0$).** Strong negative decoupling (SND) denotes the worse decoupling state where economic growth value decreases ($\%\Delta GDP < 0$) while carbon emission growth increases ($\%\Delta CO_2 > 0$). These types of economies are carbon intensive and goes against low-carbon or green economy agenda.

3.3. Decomposition of the decoupling elastic index

Having examined the decoupling statuses in all the countries under consideration to ascertain whether they are low carbon economies or carbon-intensive economies, the study goes the next step by decomposing the decoupling elastic index into its driving factors. This helps to determine the main factors that influence the growth of CO_2 emissions. This is achieved by combining the LMDI decomposition formula with the Kaya Identity proposed by Kaya [36]. This is necessary due to the deficiency of the decoupling method in this regard. The decoupling method can only identify the DR between economic growth and CO_2 emissions in a country for a given period, but cannot analyse the factors that drive such process. In contrast, the LMDI decomposition has several unique qualities that allow it to be easily merged with other models. To effectively accomplish this task, the study adopts the Kaya identity which specifies total emissions as an identity of four factors namely carbon intensity (CI), energy intensity (EI), GDP per capita, and total population. The original Kaya identity is specified in equation (2);

$$CO_2 = \frac{CO_2}{E} \ x \ \frac{E}{GDP} \ x \ \frac{GDP}{Pop} \ x \ Pop \tag{2}$$

In equation (2) CO_2 is the total carbon emissions, while $\frac{CO_2}{E} = f$, $\frac{E}{GDP} = ei$, $\frac{GDP}{P} = g$, and P respectively represent CI, EI, GDP per capita, and total population. CI is calculated as the ratio of total CO_2 emissions to total energy consumption (E), while EI denotes the ratio of total energy consumption to GDP measured at constant 2015 US$ to enable comparison among countries and avoid the effect of inflation.

However, to obtain the contribution of trade to carbon emissions, the present study augments the above expression to include two additional trade-related indexes and an index for output per carbon emission as shown in equation (3);

$$CO_2 = \frac{CO_2}{E} \ x \ \frac{E}{GDP} \ x \ \frac{GDP}{CO_2} \ x \ \frac{CO_2}{T} \ x \ \frac{T}{GDP} \ x \ \frac{GDP}{Pop} \ x \ Pop \tag{3}$$

The identity in equation (3) has three additional variables namely output per carbon emissions $\left(\frac{GDP}{CO_2} = oc\right)$, trade quality $\left(\frac{CO_2}{T} = tq\right)$, and trade intensity $\left(\frac{T}{GDP} = ti\right)$. These three variables are of particular interest to the present study as they help explore the relationship between trade and environmental quality. The output per carbon emissions also measures the efficiency of output in terms of the quantity of emissions caused during production. The study employs the additive LMDI decomposition model specified in equation (4) in line with [24,37].

$$\Delta CO_2 = CO_2^{\,T} - CO_2^{\,0} = \Delta C_f + \Delta C_{ei} + \Delta C_{oc} + \Delta C_{te} + \Delta C_{ti} + \Delta C_g + \Delta C_{pop} \tag{4}$$

where ΔCO_2 represents the change in total CO_2 emissions between the base year and the target year. The model implies that the overall change in total CO_2 emissions is explained by changes in carbon emissions factor (ΔC_f), energy intensity factor (ΔC_{ei}), output per carbon emission factor (ΔC_{oc}), trade quality factor (ΔC_{tq}), trade intensity factor (ΔC_{ti}), per capita GDP factor (ΔC_g), and population factor (ΔC_{pop}). Refer to [38,39] for the mathematical derivations of the LMDI. The additive LMDI decomposition model can be further specified as follows from equation (5) through to equation (11).

$$\Delta C_f = \frac{CO_2^{\,T} - CO_2^{\,0}}{\ln CO_2^{\,T} - \ln CO_2^{\,0}} \ln\left(\frac{f^T}{f^0}\right) for \ CO_2^{\,T} \neq CO_2^{\,0} \tag{5}$$

$$\Delta C_e = \frac{CO_2^{\,T} - CO_2^{\,0}}{\ln CO_2^{\,T} - \ln CO_2^{\,0}} \ln\left(\frac{ei^T}{ei^0}\right) for \ CO_2^{\,T} \neq CO_2^{\,0} \tag{6}$$

$$\Delta C_{oc} = \frac{CO_2^{\,T} - CO_2^{\,0}}{\ln CO_2^{\,T} - \ln CO_2^{\,0}} \ln\left(\frac{oc^T}{oc^0}\right) for \ CO_2^{\,T} \neq CO_2^{\,0} \tag{7}$$

$$\Delta C_{tq} = \frac{CO_2^{\,T} - CO_2^{\,0}}{\ln CO_2^{\,T} - \ln CO_2^{\,0}} \ln\left(\frac{tq^T}{tq^0}\right) for \ CO_2^{\,T} \neq CO_2^{\,0} \tag{8}$$

$$\Delta C_{ti} = \frac{CO_2^{\,T} - CO_2^{\,0}}{\ln CO_2^{\,T} - \ln CO_2^{\,0}} \ln\left(\frac{ti^T}{ti^0}\right) for \ CO_2^{\,T} \neq CO_2^{\,0} \tag{9}$$

$$\Delta C_g = \frac{CO_2^{\,T} - CO_2^{\,0}}{\ln CO_2^{\,T} - \ln CO_2^{\,0}} \ln\left(\frac{g^T}{g^0}\right) for \ CO_2^{\,T} \neq CO_2^{\,0} \tag{10}$$

$$\Delta C_{pop} = \frac{CO_2^{\,T} - CO_2^{\,0}}{\ln CO_2^{\,T} - \ln CO_2^{\,0}} \ln\left(\frac{pop^T}{pop^0}\right) for \ CO_2^{\,T} \neq CO_2^{\,0} \tag{11}$$

The meaning of *f, ei oc, tq, ti, g,* and *pop* remains the same as explained earlier. Having defined the decomposition indices, equation (1) can be rewritten as:

$$DI = \Delta CO_2 \times \frac{GDP^{\,0}}{CO_2^{\,0} \times \Delta GDP} \tag{12}$$

Embedding LMDI decomposition into equation (12) gives equation (13):

$$DI = \left(\Delta C_f + \Delta C_{ei} + \Delta C_{oc} + \Delta C_{te} + \Delta C_{ti} + \Delta C_g + \Delta C_{pop}\right) \times \frac{GDP^{\,0}}{CO_2^{\,0} \times \Delta GDP} \tag{13}$$

We are now able to decompose the decoupling elasticity index to identify the drivers of the decoupling process, following the approach adopted by Ref. [39]. This gives seven (7) primary factors explaining the decoupling of CO_2 from economic growth in the selected countries (see equation 14). These include: carbon emissions factor, energy intensity factor, output per carbon emission factor, trade quality factor, trade intensity factor, per capita GDP factor, and population factor. The respective equations for extracting the 7 primary identities are presented by equations (15)–(21), respectively, such that:

$$DI = DC_f + DC_{ei} + DC_{oc} + DC_{te} + DC_{ti} + DC_g + DC_{pop} \tag{14}$$

$$DC_f = \frac{CO_2{}^T - CO_2{}^0}{\ln CO_2{}^T - \ln CO_2{}^0} \ln\left(\frac{f^T}{f^0}\right) \times \frac{GDP^0}{CO_2{}^0 \times \Delta GDP} \tag{15}$$

$$DC_{ei} = \frac{CO_2{}^T - CO_2{}^0}{\ln CO_2{}^T - \ln CO_2{}^0} \ln\left(\frac{ei^T}{ei^0}\right) \times \frac{GDP^0}{CO_2{}^0 \times \Delta GDP} \tag{16}$$

$$DC_{oc} = \frac{CO_2{}^T - CO_2{}^0}{\ln CO_2{}^T - \ln CO_2{}^0} \ln\left(\frac{oc^T}{oc^0}\right) \times \frac{GDP^0}{CO_2{}^0 \times \Delta GDP} \tag{17}$$

$$DC_{tq} = \frac{CO_2{}^T - CO_2{}^0}{\ln CO_2{}^T - \ln CO_2{}^0} \ln\left(\frac{tq^T}{tq^0}\right) \times \frac{GDP^0}{CO_2{}^0 \times \Delta GDP} \tag{18}$$

$$DC_{ti} = \frac{CO_2{}^T - CO_2{}^0}{\ln CO_2{}^T - \ln CO_2{}^0} \ln\left(\frac{ti^T}{ti^0}\right) \times \frac{GDP^0}{CO_2{}^0 \times \Delta GDP} \tag{19}$$

$$DC_g = \frac{CO_2{}^T - CO_2{}^0}{\ln CO_2{}^T - \ln CO_2{}^0} \ln\left(\frac{g^T}{g^0}\right) \times \frac{GDP^0}{CO_2{}^0 \times \Delta GDP} \tag{20}$$

$$DC_{pop} = \frac{CO_2{}^T - CO_2{}^0}{\ln CO_2{}^T - \ln CO_2{}^0} \ln\left(\frac{pop^T}{pop^0}\right) \times \frac{GDP^0}{CO_2{}^0 \times \Delta GDP} \tag{21}$$

Table 2
Decoupling states for sub-Sahara African (SSA) countries.

Country	1998–2002		2002–2006		2006–2010		2010–2014		2014–2018	
Angola	0.800	EC	0.952	EC	1.048	EC	1.015	EC	0.739	WD
Benin	2.753	END	4.820	END	4.611	END	3.218	END	3.687	END
Botswana	0.502	WD	0.249	WD	−0.126	SD	0.819	EC	0.918	EC
Burkina Faso	0.732	WD	1.013	EC	1.452	END	1.690	END	1.888	END
Burundi	−0.943	SD	−1.143	SD	1.075	EC	1.120	EC	2.692	END
Cabo Verde	2.040	END	2.615	END	1.930	END	1.543	END	1.666	END
Cameroon	−0.437	SD	0.067	WD	0.545	WD	0.158	WD	0.213	WD
Central African Rep.	0.930	EC	0.819	EC	0.428	WD	−15.035	SND	2.689	END
Chad	0.663	WD	0.643	WD	0.693	WD	0.426	WD	0.579	WD
Comoros	1.214	END	2.225	END	1.693	END	1.156	EC	2.145	END
Congo, Dem. Rep.	3.322	RD	1.545	END	1.349	END	2.852	END	0.504	WD
Congo, Rep.	−0.967	SD	1.398	END	0.794	WD	0.262	WD	−0.005	SD
Cote d'Ivoire	−8.081	SND	−8.406	SND	1.924	END	2.044	END	1.209	END
Eswatini	−0.585	SD	−0.339	SD	−0.236	SD	−0.234	SD	−0.054	SD
Gabon	1.357	RD	2.789	RD	−1.160	SD	0.418	WD	−0.175	SD
Gambia, The	1.342	END	1.591	END	1.313	END	1.970	END	1.513	END
Ghana	1.225	END	0.808	EC	0.922	EC	0.842	EC	0.758	WD
Guinea	1.241	END	1.571	END	1.887	END	0.873	EC	0.958	EC
Guinea-Bissau	−1.515	SD	1.564	END	1.116	EC	1.253	END	0.987	EC
Kenya	0.491	WD	0.964	EC	1.351	END	1.253	END	1.254	END
Madagascar	−20.527	SD	0.021	WD	0.358	WD	1.551	END	1.340	END
Mali	3.188	END	2.631	END	3.041	END	2.816	END	3.979	END
Mauritania	157.162	END	1.076	EC	2.443	END	2.178	END	2.962	END
Mauritius	2.760	END	2.248	END	1.601	END	1.328	END	1.080	EC
Mozambique	0.692	WD	0.576	WD	0.826	EC	1.165	EC	1.529	END
Namibia	0.406	WD	0.563	WD	0.812	EC	0.913	EC	0.949	EC
Niger	0.000	–	0.243	WD	1.619	END	1.789	END	1.502	END
Nigeria	0.426	WD	0.287	WD	0.145	WD	0.283	WD	0.365	WD
Rwanda	0.214	WD	0.076	WD	0.126	WD	0.307	WD	0.388	WD
Senegal	1.785	END	1.523	END	1.765	END	1.803	END	1.360	END
Seychelles	9.917	END	5.910	END	0.000	–	0.086	WD	0.519	WD
Sierra Leone	4.368	END	2.493	END	1.343	END	1.764	END	1.691	END
South Africa	0.863	EC	0.778	WD	0.867	EC	0.790	WD	0.636	WD
Sudan	2.526	END	2.947	END	3.262	END	4.700	END	6.214	END
Tanzania	1.335	END	1.974	END	1.473	END	1.811	END	1.387	END
Togo	1.812	END	3.061	END	4.454	END	0.528	WD	0.906	EC
Uganda	0.706	WD	1.435	END	1.562	END	1.479	END	1.568	END
Zambia	−0.586	SD	0.008	WD	0.176	WD	0.679	WD	1.165	EC
Zimbabwe	1.008	RC	0.820	RC	0.924	RC	2.114	RD	−2.417	SD

Source: Authors' computation

4. Results and discussions

4.1. Analysis of decoupling states

The analysis of the decoupling status of CO_2 emissions from economic growth is presented for each selected country and with respect to the world regional economic blocs (see Tables 2–7). The decoupling results provides the extent to which economic growth is disentangled from carbon emissions for a country within a given time period. It also informs the dynamics of the decoupling process over time. We identified that the decoupling process can either be stable or unstable. In contrast to unstable decoupling, the stable decoupling mechanism illustrates a decoupling state which does not change over time. The evidence shows that 54 (37.24 %) of the selected countries achieved stable decoupling states, majority of which are from the ECA region (22 countries representing 40.74 %). We identified that the majority of the countries experiencing stable decoupling process over the sample period can be described as having a high decoupling mechanism[1] (31 countries; representing 57.41 %). France, Germany, Belgium, Australia, New Zealand, Cameroon, Nigeria, Chile, Costa Rica, Nicaragua, Rwanda, Israel, Jordan and Tunisia are examples of countries with stable and high decoupling state. There are also 91 countries which witnessed unstable decoupling process. We classified these countries into "unstable and improving decoupling", "unstable and deteriorating decoupling" and "unstable and alternating decoupling" countries. An alternating decoupling, here, refers, a dynamic decoupling condition which exhibits no particular pattern of the decoupling process over the study period. For example, Sri Lanka, Pakistan, Peru, United Arab Emirates, Micronesia, Botswana, and Central African Republic experienced unstable and alternating decoupling process. On the other hand, Colombia, El Salvador, Georgia, Mozambique and Niger witnessed unstable and deteriorating decoupling process over the study period. Ghana, Malta, United States, Greece, Jamaica, Egypt, Switzerland, Croatia, Uzbekistan, and Slovenia are examples of countries which achieved unstable and improving decoupling state. The distribution of the decoupling state between economic growth and CO_2 emissions shows that globally the decoupling of CO_2 from economic growth can be distinguished into seven states: WD, recessive coupling (RC), SND, SD, END, recessive decoupling (RD) and EC. Table 2 presents the distribution of decoupling states for countries within the sub-Sahara African region. The decoupling results indicate that countries in the SSA mostly performed END throughout the study period. In terms of the dynamics of the decoupling process, countries within the region have not achieved a stable decoupling state. While Cameroon, Nigeria, Rwanda, and Chad achieved a stable WD status, Benin, Cape Verde, Congo Republic, Mali, Senegal, and Sierra Leone achieved stable END state. It is important to add that while some countries (i.e., Angola, Ghana and Guinea) achieved an improvement in the decoupling dynamics, others such as Burundi, Kenya, Mauritania, Mozambique, Namibia, Niger, Madagascar, and Zambia experiences worsening decoupling progress. In general, however, unstable decoupling dynamics is observed in most countries throughout the study period.

The decoupling results for countries in the East Asia and Pacific region is also reported in Table 3. The evidence suggests that within the EAP region, while the WD state has been predominant throughout the study period, some degree of instability in the decoupling progress is evident as a result of either an improvement or worsening of the decupling process. Australia, New Zealand and South Korea attained stable WD process while Fiji, Kiribati, Lao PDR, and Vietnam attained stable weak negative decoupling (WND). Most countries attained an improvement in the decoupling process throughout the time period, while only Cambodia, Philippines, Singapore, and Vanuatu experienced a decline in the decoupling status. Only Tonga experienced an unstable decoupling process of END-END-WD-END.

With respect to countries in Europe and Central Asia, the decoupling results show that the region has performed mostly SD or WD states, except for Albania and Luxembourg that attained the END (see Table 4). Luxembourg, Spain, Turkey, and Turkmenistan also experienced periods of EC. Countries in this region have generally performed stable SD (Azerbaijan, Belgium, Denmark, France, etc.) or WD (Armenia, Belarus, Cyprus, Russia, etc.) or an unstable decoupling ranging from WD to SD (Switzerland, Uzbekistan, Slovenia, etc.), thus implying an improvement in the decoupling process, or from SD to WD (Georgia, Kyrgyz Republic, Tajikistan) indicating a worsening of the decoupling process.

Tables 5 and 6 report the decoupling status of countries in Latin America, and Middle East and North Africa regions respectively. According to the results, the WD process dominates the other decoupling states in the LAC region (Table 5). A few countries performed the END while the EC was also witnessed in Guatemala, Mexico, Peru, Ecuador, and Brazil. SD was also achieved in only three countries (Colombia, Jamaica, and Paraguay) at different time periods. In contrast, the MENA region is characterised by highly unstable decoupling dynamics throughout the study period (Table 6). Only Israel, Jordan and Tunisia achieved SD while Morocco performed stable EC state. The other countries performed unstable decoupling state ranging from END through SD. While some experienced an improvement in the decoupling performance (Malta, Egypt and Qatar), others deteriorated (Lebanon, Iraq, and Algeria).

Table 7 provides the decoupling results for countries in the North America and the South Asia regions. The United States and Canada generally performed better decoupling processes. The dynamic pattern of decoupling process for United States shows a stable SD process from 2006 to 2018; whereas Canada achieved a stable WD status throughout the study period. With respect to countries in the South Asian region, the evidence suggests that most of the selected countries witnessed an alternating decoupling process except Bangladesh which performed a stable END.

[1] High decoupling process refers to all countries which have a decoupling status of weak decoupling to strong decoupling process; whereas Low decoupling process is defined as all other decoupling state.

Table 3
Decoupling states for countries in East Asia and Pacific.

Country	1998–2002		2002–2006		2006–2010		2010–2014		2014–2018	
Australia	0.489	WD	0.455	WD	0.384	WD	0.198	WD	0.218	WD
Cambodia	0.324	WD	0.454	WD	0.916	EC	0.953	EC	1.301	END
China	0.468	WD	0.899	EC	0.742	WD	0.614	WD	0.467	WD
Fiji	1.427	END	3.317	END	1.957	END	1.549	END	2.097	END
Indonesia	1.183	EC	0.972	EC	0.784	WD	0.732	WD	0.736	WD
Japan	2.340	END	0.515	WD	0.262	WD	0.629	WD	−0.126	SD
Kiribati	4.775	END	10.574	END	5.397	END	4.221	END	3.312	END
Lao PDR	1.302	END	1.495	END	1.995	END	2.126	END	7.314	END
Malaysia	1.442	END	1.257	END	1.147	EC	1.011	EC	0.770	WD
Micronesia	0.839	EC	0.803	EC	−1.805	SD	2.258	END	3.121	END
Mongolia	0.990	EC	0.824	EC	0.707	WD	0.533	WD	0.560	WD
New Zealand	0.885	EC	0.711	WD	0.344	WD	0.288	WD	0.223	WD
Philippines	−0.174	SD	−0.129	SD	0.159	WD	0.334	WD	0.493	WD
Singapore	0.481	WD	−0.036	SD	0.113	WD	0.117	WD	0.135	WD
Solomon Islands	−0.768	SND	−12.383	SND	3.007	END	1.458	END	1.108	EC
South Korea	0.706	WD	0.521	WD	0.620	WD	0.515	WD	0.504	WD
Thailand	0.873	EC	0.811	EC	0.721	WD	0.719	WD	0.537	WD
Tonga	0.000	–	3.691	END	1.432	END	0.390	WD	2.230	END
Vanuatu	0.000	–	−0.608	SD	1.705	END	2.105	END	1.797	END
Vietnam	1.813	END	1.691	END	2.078	END	1.671	END	1.950	END

Source: Authors' computation

4.2. Comparing regional decoupling performance

From the country-specific trends, we compare the average trends in decoupling across regional blocs. The results in Fig. 3 indicate that the SD state was the most observed (i.e., 57.8 %) in the ECA region throughout the study period. In North America, the occurrence of the SD and WD states were respectively 30 % and 70 %. The regions with the most occurrence of the WD are NA (70 %), LAC (48.9 %), EAP (41.8 %), and ECA (34.7 %), while only (32.5 %), (28 %), and (24.4 %) of countries in MENA, SA, and SSA achieved the WD status. Regarding the EC decoupling status, SA, MENA, LAC, SSA, and EAP also report relatively significant shares of about 32 %, 26.3 %, 21.1 % 16.1 %, and 15.3 % respectively. While the NA region report no occurrence of both the EC and END statuses, the ECA region observed relatively small proportions (4.4 %) of the END state. The SSA, SA, EAP, MENA, and LAC regions observed the most END state in ascending order. The SSA region achieved about 45.6 % END while about 40 %, 34.7 %, 31.3 % and 17.8 % were achieved in the SA, EAP, MENA and the LAC regions respectively.

Implication from the regional analysis is that countries in developed regions (i.e., ECA and NA) perform better decoupling of economic growth from CO_2 emissions compared with developing and emerging regions like the SSA, LAC, MENA, and SA. While the developed countries care more about environmental quality, governments in developing countries prioritise industrialization to increase economic growth of their economies to help reduce poverty and improve the living conditions of their people. This finding is consistent with the proposition of the EKC hypothesis and empirical findings by Refs. [12,13,15]. Despite the heterogeneity in countries within and across regions, it is observed that countries within a region generally have similarities in decoupling state achieved throughout the study period. The results further point to the fact that the structural frameworks in countries within a region are relatively similar compared to countries in different regions.

4.3. Decomposition analysis of the driving factors of total changes in CO_2 emissions

This section discusses how changes in key indexes affect the change in overall level of CO_2 emissions, and compares the differences in such effects across the different regions considered in this study. The section only presents the regional bloc comparison as shown in Figs. 4 and 5, while the individual country decomposition results are presented in the appendix (Fig. I – VII). The results presented in Fig. 4 indicate that the activity effect and population effect are the main drivers of total change in CO_2 emissions across the different regions considered in this study. However, the average contribution of these factors differs from one region to another. For instance, while activity or scale effect is the main driver of CO_2 emissions increase in the EAP and SA regions, population effect contribute the most to total CO_2 emissions in the MENA and SSA regions. In the ECA and NA regions however, output per carbon emissions effect is the main cause of total change in carbon emissions. Focusing on the contribution of trade liberalization on CO_2 emissions, the analysis show that trade efficiency inhibits the growth in CO_2 emissions in all regions over the study period. Regions where the inhibiting effect of trade efficiency was highest are ECA, LAC and NA.

In contrast, trade intensity displayed both inhibiting and promotion effect on growth in CO_2 emissions. For countries in SSA and EAP, the result suggests trade intensity and trade efficiency play complementary roles in reducing the growth in CO_2 emissions in the sample period. However, for countries in ECA, LAC, MENA, NA and SA, trade efficiency and trade intensity display diverging roles. The promotion effect of trade intensity is however offset by the inhibiting effect of trade efficiency over the period. To understand the dynamic trend in the contribution of the observed factors in each region, a disintegration of the cumulative index based for each period was performed. Fig. 5 provides the trend and dynamics of the performance of the indexes towards overall change in CO_2 emission

Table 4
Decoupling states for Europe and Central Asian countries.

Country	1998–2002		2002–2006		2006–2010		2010–2014		2014–2018	
Albania	2.954	END	1.784	END	1.434	END	1.557	END	1.364	END
Armenia	−0.282	SD	0.244	WD	0.185	WD	0.317	WD	0.260	WD
Austria	0.713	WD	0.698	WD	0.331	WD	−0.138	SD	−0.057	SD
Azerbaijan	−0.074	SD	−0.067	SD	−0.104	SD	−0.040	SD	−0.044	SD
Belarus	−0.469	SD	0.038	WD	0.060	WD	0.027	WD	0.025	WD
Belgium	−0.688	SD	−0.424	SD	−0.397	SD	−0.741	SD	−0.514	SD
Bulgaria	−2.591	SD	−0.092	SD	−0.227	SD	−0.301	SD	−0.252	SD
Croatia	0.883	EC	0.507	WD	0.174	WD	−0.430	SD	−0.237	SD
Cyprus	0.428	WD	0.506	WD	0.355	WD	0.081	WD	0.150	WD
Czech Republic	−0.032	SD	0.039	WD	−0.095	SD	−0.329	SD	−0.185	SD
Denmark	−1.178	SD	−0.138	SD	−1.263	SD	−1.994	SD	−1.332	SD
Estonia	−0.358	SD	−0.032	SD	0.304	WD	0.125	WD	−0.015	SD
Finland	0.708	WD	0.555	WD	0.291	WD	−0.619	SD	−0.541	SD
France	−0.242	SD	−0.128	SD	−0.402	SD	−0.753	SD	−0.535	SD
Georgia	−2.574	SD	−0.092	SD	0.071	WD	0.505	WD	0.505	WD
Germany	−0.542	SD	−0.481	SD	−0.737	SD	−0.652	SD	−0.561	SD
Greece	0.683	WD	0.422	WD	0.019	WD	−4.747	SD	−3.906	SD
Hungary	−0.172	SD	−0.084	SD	−0.500	SD	−0.695	SD	−0.293	SD
Iceland	0.294	WD	0.200	WD	−0.215	SD	−0.085	SD	0.027	WD
Ireland	0.399	WD	0.366	WD	0.085	WD	−0.104	SD	−0.024	SD
Italy	0.514	WD	0.764	WD	−0.562	SD	−5.334	SD	−2.560	SD
Kazakhstan	−0.168	SD	0.367	WD	0.478	WD	0.273	WD	0.283	WD
Kyrgyz Republic	−1.165	SD	−0.330	SD	0.084	WD	0.612	WD	0.610	WD
Latvia	−0.406	SD	0.011	WD	0.084	WD	−0.132	SD	−0.059	SD
Lithuania	−1.431	SD	−0.195	SD	−0.252	SD	−0.307	SD	−0.193	SD
Luxembourg	1.284	END	1.270	END	0.835	EC	0.397	WD	0.263	WD
Moldova	−1.322	SD	−0.170	SD	−0.065	SD	−0.113	SD	−0.006	SD
Netherlands	0.028	WD	−0.091	SD	0.100	WD	−0.370	SD	−0.236	SD
North Macedonia	−2.005	SD	−0.195	SD	−0.252	SD	−0.361	SD	−0.332	SD
Norway	−0.904	SD	−0.022	SD	0.499	WD	0.063	WD	−0.012	SD
Poland	−0.749	SD	−0.039	SD	−0.024	SD	−0.131	SD	−0.016	SD
Portugal	1.665	END	0.604	WD	−0.524	SD	−1.879	SD	−0.504	SD
Romania	−0.431	SD	−0.010	SD	−0.405	SD	−0.388	SD	−0.227	SD
Russia	0.179	WD	0.171	WD	0.133	WD	0.122	WD	0.116	WD
Slovak Republic	−0.886	SD	−0.212	SD	−0.222	SD	−0.342	SD	−0.197	SD
Slovenia	0.008	WD	0.139	WD	0.047	WD	−0.353	SD	−0.145	SD
Spain	1.267	END	0.966	EC	0.187	WD	−0.196	SD	0.018	WD
Sweden	−0.562	SD	−0.538	SD	−0.490	SD	−0.738	SD	−0.624	SD
Switzerland	−0.206	SD	0.153	WD	0.078	WD	−0.273	SD	−0.312	SD
Tajikistan	−0.627	SD	−0.036	SD	−0.085	SD	0.276	WD	0.511	WD
Turkey	1.946	END	0.857	EC	0.995	EC	0.730	WD	0.768	WD
Turkmenistan	1.068	EC	0.836	EC	0.554	WD	0.424	WD	0.327	WD
Ukraine	−0.082	SD	−0.027	SD	−0.212	SD	−0.440	SD	−0.809	SD
United Kingdom	0.088	WD	0.134	WD	−0.354	SD	−0.633	SD	−0.702	SD
Uzbekistan	0.593	WD	0.141	WD	0.071	WD	−0.041	SD	−0.006	SD

Source: Authors' computation

throughout the study period. The results show that while the contribution of trade efficiency is generally declining over the study period, its contribution in the growth of total CO_2 emissions is stronger than trade intensity. Activity effect however dominate across most regions except MENA, and NA. There were changes (magnitude and direction) of the impact of the indexes on overall change in CO_2 emissions. Trade efficiency was the main contributor to emission reduction (panel titled "All countries") as well as in the ECA and NA regions throughout the study period. The dynamics of the contribution of the factors have generally been inconsistent for other regions in the study period including the trade indexes. This implies that the nature of trade policies varies from one region to another. While trade efficiency significantly reduces overall emission levels in some regions (ECA and NA), its effect on emission reduction has been largely inconsistent in the other regions. CI has also contributed to an insignificant reduction of the overall change in carbon emissions. These results confirm the results obtained by Ref. [15].

4.3.1. Decomposition analysis of the decoupling elasticity

This section analyses the drivers of the decoupling elastic indicator. For brevity and due to lack of space, we present the results for few countries, specifically the SSA countries (Fig. 6) and ECA countries (Fig. 7). We also limit the discussion in this section to the two policy indexes of interest – trade intensity and trade efficiency effects. The detailed results are found in the appendix section. However, the general observation is that changes in economic activity, output per carbon emissions and population inhibited the decoupling process in several countries. For countries in the EAP such as Cambodia, Fiji, Kiribati, New Zealand and Tonga; as well as some few countries in LAC (e.g., Jamaica and El Salvador) output per carbon emissions exhibited an oscillating contribution to the decoupling process (see Fig. IX & XI in the appendix section). Further, growth in EI and CI were observed to promote the decoupling process in

Table 5
Decoupling states for Latin America and the Caribbean (LAC) countries.

Country	1998–2002		2002–2006		2006–2010		2010–2014		2014–2018	
Argentina	0.642	WND	1.195	EC	0.774	WD	0.872	EC	0.805	EC
Brazil	0.952	EC	0.577	WD	0.728	WD	1.140	EC	0.799	WD
Chile	−0.451	SD	0.273	WD	0.608	WD	0.554	WD	0.653	WD
Colombia	−4.327	SD	−0.385	SD	0.020	WD	0.311	WD	0.251	WD
Costa Rica	0.628	WD	0.751	WD	0.624	WD	0.597	WD	0.522	WD
Dominican Republic	1.371	END	0.513	WD	0.328	WD	0.265	WD	0.312	WD
Ecuador	0.210	WD	0.894	EC	1.091	EC	0.965	EC	0.828	EC
El Salvador	0.812	EC	1.692	END	0.734	WD	0.475	WD	0.423	WD
Guatemala	1.835	END	1.230	END	0.771	WD	0.928	EC	1.226	END
Haiti	9.157	END	2.662	END	4.386	END	3.869	END	3.323	END
Honduras	2.232	END	1.660	END	1.247	END	1.218	END	0.936	EC
Jamaica	1.015	EC	1.615	END	−2.569	SD	−2.074	SD	−0.715	SD
Mexico	0.569	WD	0.978	EC	1.043	EC	0.577	WD	0.488	WD
Nicaragua	0.984	EC	0.791	WD	0.577	WD	0.414	WD	0.457	WD
Panama	−0.556	SD	0.716	WD	0.683	WD	0.611	WD	0.360	WD
Paraguay	2.566	RD	−0.937	SD	0.473	WD	0.505	WD	1.088	EC
Peru	0.322	WD	0.436	WD	0.897	EC	0.824	EC	0.688	WD
Uruguay	1.473	RD	9.259	END	0.292	WD	0.237	WD	0.217	WD

Source: Authors' computation

Table 6
Decoupling states for Middle East and North African (MENA) countries.

Country	1998–2002		2002–2006		2006–2010		2010–2014		2014–2018	
Algeria	0.477	WD	0.639	WD	0.919	EC	1.112	EC	1.094	EC
Egypt	0.863	EC	1.263	END	0.984	EC	1.002	EC	0.917	EC
Iran	1.666	END	1.606	END	1.364	END	1.715	END	1.470	END
Iraq	−0.089	SD	0.088	WD	0.761	WD	0.934	EC	0.829	EC
Israel	1.468	END	0.785	WD	0.676	WD	0.309	WD	0.181	WD
Jordan	0.773	WD	0.649	WD	0.391	WD	0.622	WD	0.493	WD
Kuwait	5.506	END	1.180	EC	1.579	END	1.201	END	1.366	END
Lebanon	0.439	WD	−0.005	SD	0.373	WD	0.568	WD	0.731	WD
Libya	−12.968	SND	0.599	WD	0.738	WD	−4.235	SND	3.391	END
Malta	−0.078	SD	0.293	WD	0.149	WD	−0.009	SD	−0.238	SD
Morocco	1.660	END	1.199	EC	1.088	EC	1.029	EC	0.951	EC
Oman	5.341	END	6.649	END	3.886	END	3.830	END	3.529	END
Qatar	6.135	END	1.516	END	0.873	EC	0.859	EC	0.909	EC
Saudi Arabia	−6.569	SND	1.564	END	2.179	END	1.779	END	1.400	END
Tunisia	0.885	EC	0.656	WD	0.664	WD	0.655	WD	0.631	WD
United Arab Emirates	0.921	EC	0.716	WD	1.411	END	1.143	EC	1.076	EC

Source: Authors' computation

Table 7
Decoupling states for North America (NA) and South Asian (SA) countries.

Country	1998–2002		2002–2006		2006–2010		2010–2014		2014–2018	
Canada	0.552	WD	0.319	WD	0.217	WD	0.252	WD	0.245	WD
United States	0.005	WD	0.043	WD	−0.120	SD	−0.216	SD	−0.197	SD
Bangladesh	2.099	END	1.708	END	1.817	END	1.633	END	1.504	END
India	0.765	WD	0.666	WD	0.841	EC	0.882	EC	0.714	WD
Nepal	1.239	END	0.365	WD	1.592	END	2.230	END	3.069	END
Pakistan	0.914	EC	0.994	EC	0.874	EC	0.777	WD	0.969	EC
Sri Lanka	2.444	END	0.989	EC	0.624	WD	0.774	WD	0.860	EC

Source: Authors' computation

several economies over the period across all the regions (see Fig. X – XI in the appendix section).

Concerning the role of trade intensity and trade efficiency, the evidence suggests an alternating relationship in the contributions of trade intensity and trade efficiency. For instance, focusing on SSA countries, results presented in Fig. 6 indicate a mix effect of both trade intensity and trade efficiency on the decoupling elastic index. While trade intensity influences the decoupling index positively in some countries (Angola, Botswana, Cape Verde, and The Gambia among others), trade efficiency positively drives the decoupling process in a few countries (Benin, Nigeria, Mali, Zambia, etc) within the SSA region. This implies that while trade efficiency is good in decoupling growth from CO_2 emissions, it is also possible for trade intensity to facilitate such process. It is also identified that in

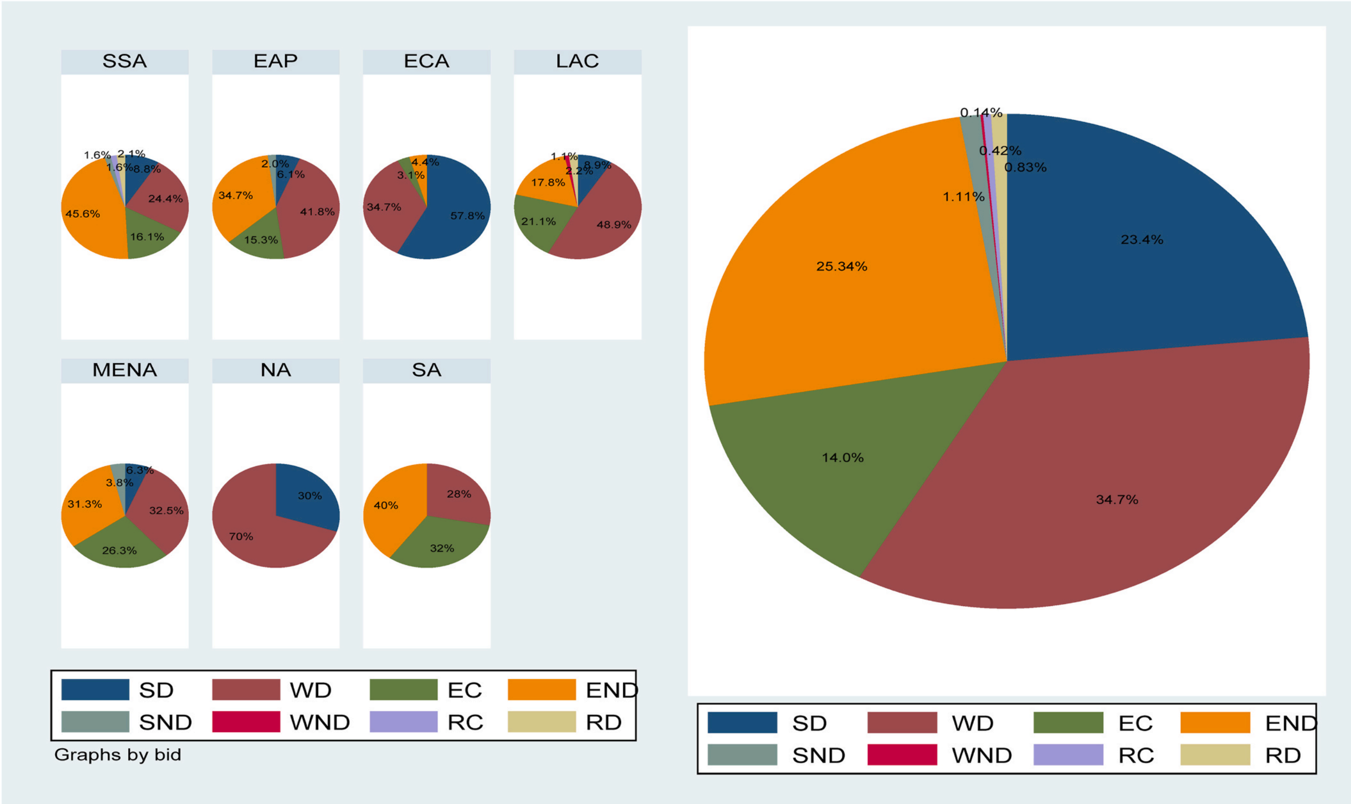

Fig. 3. Regional decoupling comparison.

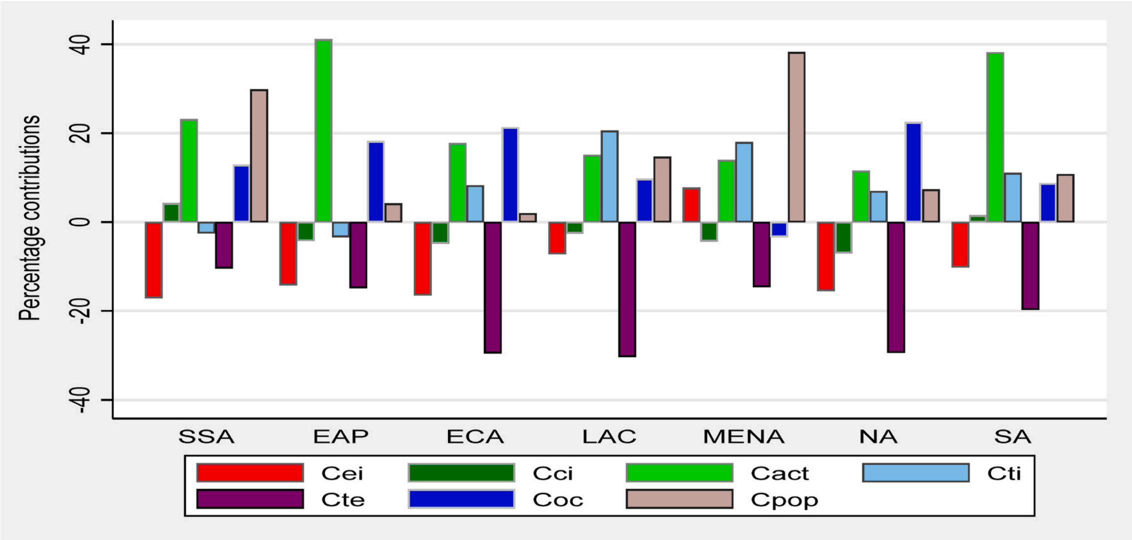

Fig. 4. Drivers of CO_2 emissions – Cumulative Index (1998–2018).

countries such as Benin, Botswana, Niger, Comoros and Rwanda where the contribution of trade intensity outperforms trade efficiency, the decoupling process was stable for several years in the study period. This observation is consistent for non-SSA countries including Australia, Japan, South Korea, Vietnam, Kuwait and Nicaragua (see Tables 3–5 after Fig. IX - XIV in the appendix section). For some few countries such as Lithuania and Poland, the outperformance of trade intensity relative to trade efficiency enforced a SD status (see Fig. 7).

The results in Fig. 7 highlights the fact that even though trade intensity drives the decoupling process in a few countries including Austria, Belgium, North Macedonia, Poland, Sweden, and among others, trade efficiency plays an important role in influencing the decoupling elastic index positively in most countries within the ECA region where the majority of the countries were achieving stable SD or WD status for a significant number of years in the sample period. Some of such countries include Albania, Moldova, Turkmenistan, Spain, and Tajikistan among others. Comparing SSA with ECA, it is evident that trade efficiency or quality plays a key role in ECA relative to the SSA region in the period considered for the study. This observation is intuitive given that the ECA region is composed mainly of developed and high-income economies that prioritise environmental quality. As a result, such policies are incorporated into their trade policies to ensure that environmental sustainability is achieved simultaneously with increasing growth through trade liberalization. Conversely, most countries in the SSA region are developing and emerging ones, with priority on industrialising their domestic economies. Governments in these countries are thus reluctant in effectively enforcing such environmental policies that are key for pollution reduction towards achieving low-carbon targets.

5. Conclusion

The rise in global CO_2 emissions and its implications on environmental sustainability and climate change necessitated the current study. In this study, we analysed the DR between economic growth and CO_2 emissions across countries by sub-categorizing the countries based on regional blocs. This approach enabled the study to compare the decoupling performance of countries from different regions. The study also examined and compared the driving factors of total carbon emissions. To effectively achieve this goal, panel data on 145 countries from 1998 to 2018 was employed. The TD model was adopted to analyse the DR between CO_2 emissions and economic growth. The LMDI decomposition method of IDA was then combined with the augmented Kaya identity to examine the influencing factors of overall CO_2 emissions. Last, we examined the relative impacts of trade intensity and trade efficiency on the DR between economic growth and CO_2 emissions. The results from the regional decoupling analysis showed that developing regions (i.e., SSA, EAP, LAC, MENA, and SA) generally performed END, EC, and WD, and the decoupling process was largely unstable. The ECA and NA regions on the other hand, which are typically composed of developed economies performed stable WD and SD statuses throughout the study period. This result is consistent with the EKC hypothesis and the empirical findings of Refs. [12,13,15]. Regarding the influencing factors of total CO_2 emissions, the LMDI decomposition results showed that activity, trade intensity, population and output per carbon emissions effects were the main factors that enhanced CO_2 emissions. Trade quality effect on the other hand was a major factor that hindered CO_2 emissions followed by EI and CI. This results, however, vary from one region to another. The study findings also corroborate the evidence of Refs. [15,40,41].

Policy implications

The following policies are proposed based on the empirical findings obtained in this study. First, since developed regions achieved

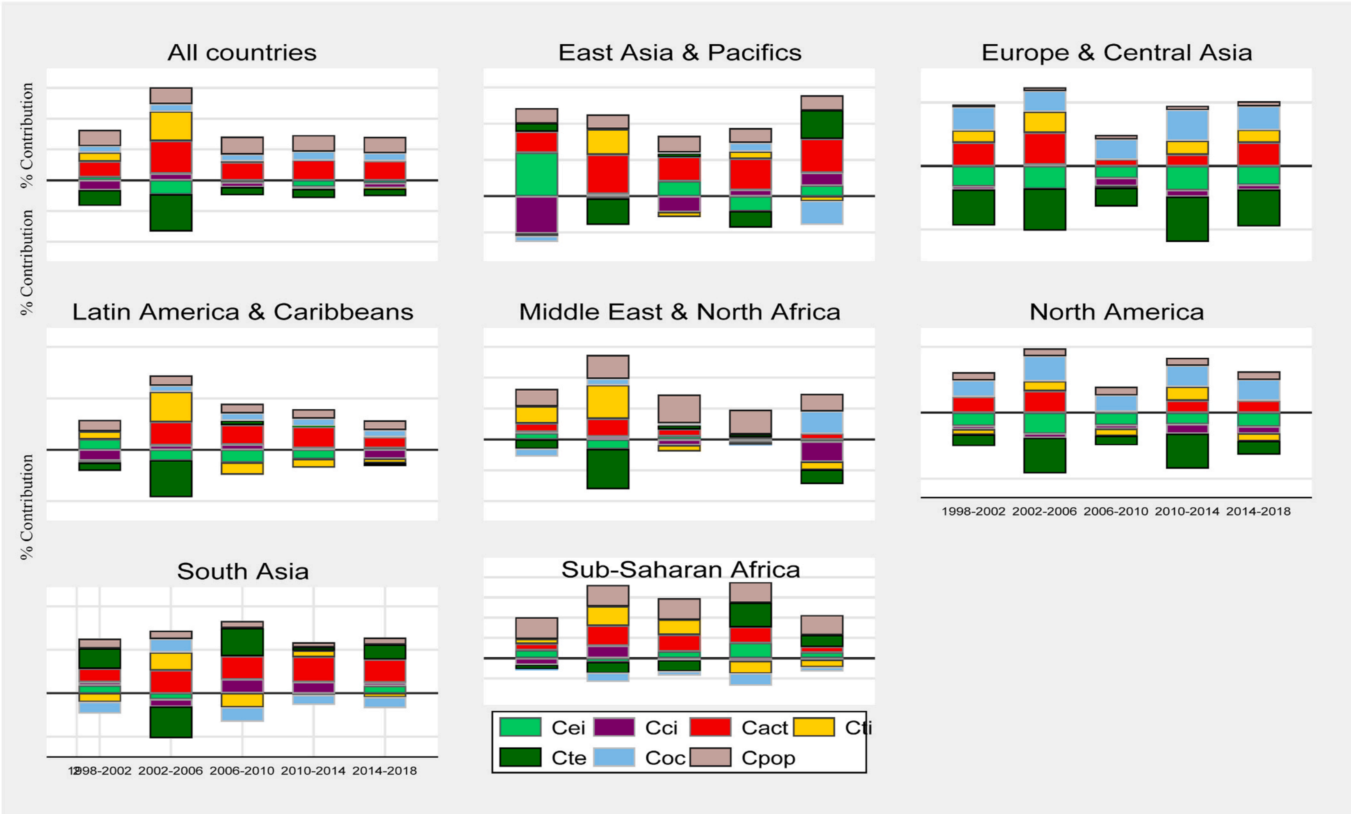

Fig. 5. Drivers of CO_2 emissions – Period-by-Period Trends (1998–2018).

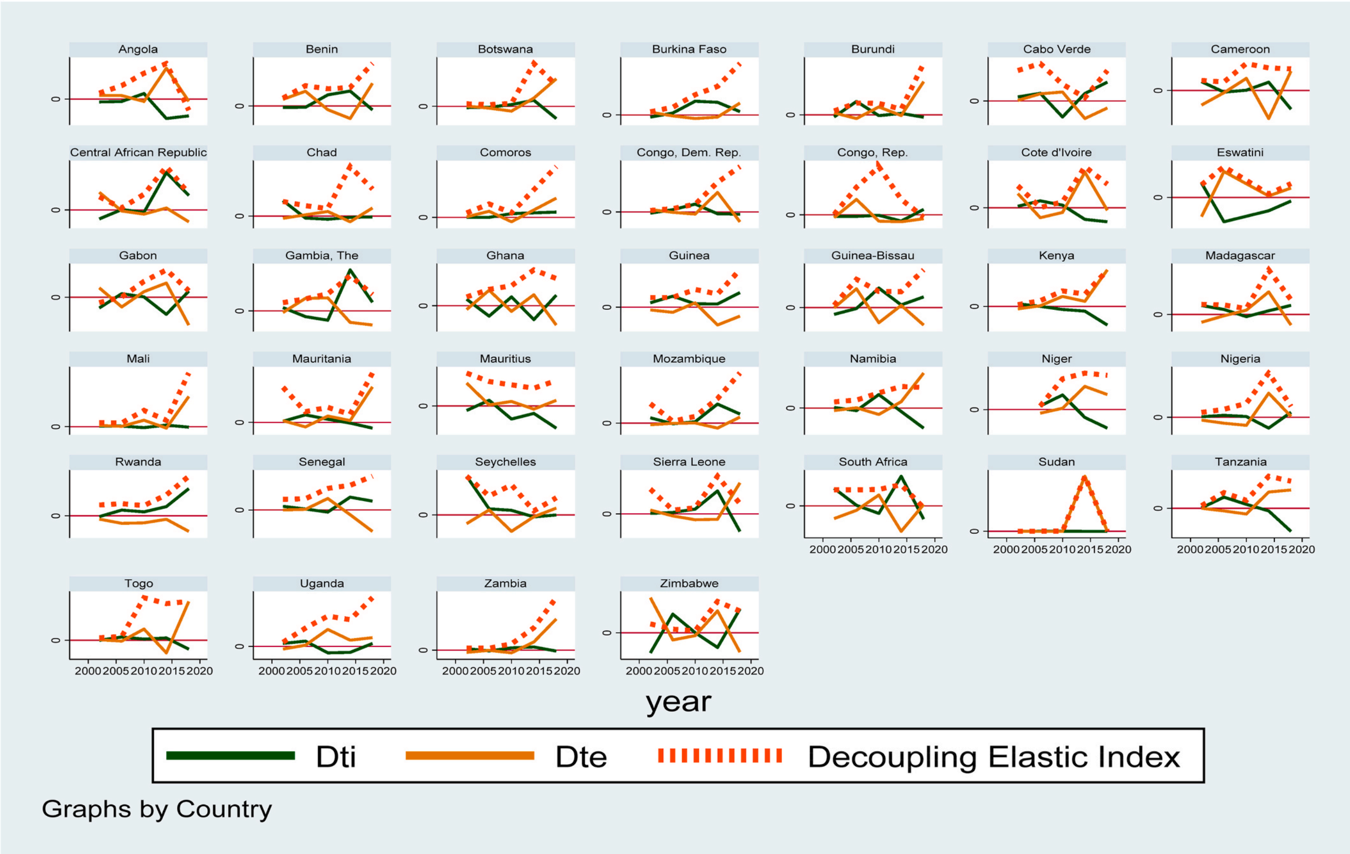

Fig. 6. Drivers of Decoupling between CO_2 emissions and Economic Growth in SSA.

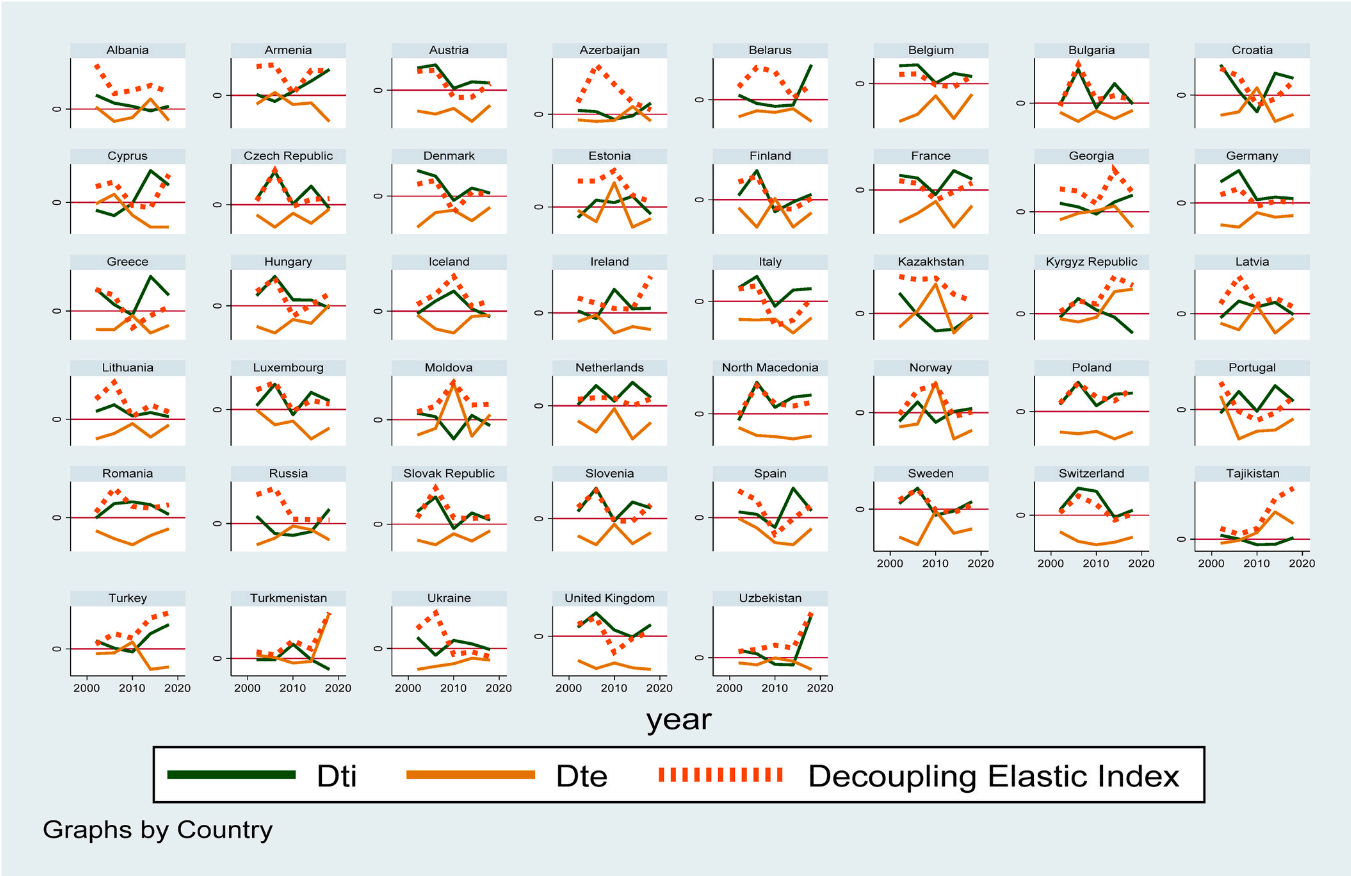

Fig. 7. Drivers of Decoupling between CO_2 emissions and Economic Growth in ECA.

better decoupling compared with developing and emerging regions, it is imperative that sustainability policies that fosters a cooperative relationship between these rich countries and the poor ones be encouraged. Such cooperation will facilitate the transfer of advanced, greener and energy-saving technology from the developed to the developing countries. This will allow developing countries to grow their respective economies while limiting the emission of harmful gases into the atmosphere.

Again, given that the regional location of countries played a significant influence on their decoupling performances, emission reduction targets should not be the sole responsibility of individual countries. Instead, a comprehensive approach must be adopted, with policies aimed at decarbonizing growth within specific regions. By implementing all-encompassing measures, it is possible to foster environmental sustainability across multiple economies within a region. The empirical results further reveal that trade quality does not promote the decoupling process in most developing regions such as the SSA, LAC, SA, EAP. This is because of the failure or inability of the developing countries to implement stringent environmental laws to regulate pollution so as to attract foreign investments into their respective domestic economies, increase their industrial output and overall economic Growth. Developing countries should emphasize on clean production processes in their trade with external bodies to attract investments that will not only bolster their industrial output and overall economic growth but also enhance environment quality. Moreover, developing countries are strongly encouraged to focus on optimizing customs procedures and providing comprehensive trade facilitation support for the import and export of clean technologies and renewable energy equipment. Such measures can effectively simplify access to and utilization of environmentally friendly solutions for businesses, rendering them more cost-effective. Furthermore, it is essential for developing countries to actively engage in trade agreements that incorporate robust environmental sustainability provisions. These agreements should encompass firm commitments to carbon emissions reduction, the promotion of clean technologies, and stringent adherence to established environmental standards. As part of these agreements, trade partners can consider offering preferential access to markets for products that meet eco-friendly criteria, incentivizing the development and trade of environmentally responsible goods.

Third, since the activity and output per emissions effect hinders the decoupling process in most countries, it is important that countries employ energy-efficient technologies that help increase output while reducing emission levels, especially the developing ones. Population control measures are needed to ensure environmental sustainability in most developing regions. This is needed to match the growth of the population with the available structures without negatively affecting environmental sustainability.

Direction for future research

Even though this study contributes immensely to both literature and policy issues, it is not without some limitations. First, the study failed to incorporate the global economic shocks such as the global credit crunch on global decoupling and trade intensity. Even though the study attempted to conduct a longitudinal trend analysis of decoupling states from 1998 to 2018, the analysis of the effect on global economic shocks on decoupling was beyond the scope of the study. It is therefore a recommendation of this study for future researchers to assess how global economic shocks, such as financial crises or pandemics, impact decoupling efforts. Specifically, it will be insightful to also explore whether economic downturns affect emissions reduction and sustainable growth. This will provide a guide to effectively understand global decoupling performance and the role the global economy plays in shaping the decoupling process. Second, while it was the key objective of this study to examine the effect of trade liberalization on decoupling state and performance, it will be important to further ascertain the impact of trade agreements with environmental provisions on decoupling performance. Future research can explore how such agreements influence trade patterns, technology transfer, and emissions reduction. It will be also insightful to investigate the role of technological innovation and R&D investment in achieving decoupling.

Data availability

The data associated with your study has not been deposited into any publicly available repository. It will however be made available upon request.

Author contributions

Kofi Amanor: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis. Franklin Bedakiyiba Baajike: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. John Bosco Dramani: Visualization, Supervision. Eric Fosu Oteng-Abayie: Validation, Supervision, Conceptualization

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e23470.

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