UNIVERSITY OF BIRMINGHAM
University of Birmingham
Research at Birmingham

Environmental sustainability of the Nigeria transport sector through decomposition and decoupling analysis with future framework for sustainable transport pathways

Abam, Fidelis I.; Ekwe, Ekwe B.; Diemuodeke, Ogheneruona E.; Ofem, Michael I.; Okon, Bassey B.; Kadurumba, Chukwuma H.; Archibong-Eso, Archibong; Effiom, Samuel O.; Egbe, Jerome G.; Ukueje, Wisdom E.

DOI:
10.1016/j.egyr.2021.05.044

License:
Creative Commons: Attribution-NonCommercial-NoDerivs (CC BY-NC-ND)

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (Harvard):
Abam, FI, Ekwe, EB, Diemuodeke, OE, Ofem, MI, Okon, BB, Kadurumba, CH, Archibong-Eso, A, Effiom, SO, Egbe, JG & Ukueje, WE 2021, 'Environmental sustainability of the Nigeria transport sector through decomposition and decoupling analysis with future framework for sustainable transport pathways', *Energy Reports*, vol. 7, pp. 3238-3248. https://doi.org/10.1016/j.egyr.2021.05.044

Link to publication on Research at Birmingham portal

General rights
Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

•Users may freely distribute the URL that is used to identify this publication.
•Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
•User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
•Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy
While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Download date: 02. May. 2024

Energy Reports 7 (2021) 3238–3248

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Research paper

Environmental sustainability of the Nigeria transport sector through decomposition and decoupling analysis with future framework for sustainable transport pathways

Fidelis I. Abam [a,*], Ekwe B. Ekwe [a], Ogheneruona E. Diemuodeke [b], Michael I. Ofem [c], Bassey B. Okon [d], Chukwuma H. Kadurumba [a], Archibong Archibong-Eso [c], Samuel O. Effiom [c], Jerome G. Egbe [e], Wisdom E. Ukueje [a]

[a] Energy, Exergy and Environment Research Group (EEERG) Department of Mechanical Engineering, Michael Okpara University of Agriculture, Umudike P.M.B., 7267, Umuahia, Nigeria
[b] Energy and Thermofluids Research Group, Department of Mechanical Engineering, University of Port Harcourt, PMB 5323, Choba, Rivers State, Nigeria
[c] Department of Mechanical Engineering, Cross River University of Technology, Calabar, P.M.B 1123 Calabar, Nigeria
[d] Department of Mechanical Engineering, Akwa Ibom State University, Ikot Akpaden, P. M.B 1167 Uyo, Nigeria
[e] Department of Civil Engineering, Cross River University of Technology, Calabar, P.M.B 1123 Calabar, Nigeria

ARTICLE INFO

Article history:
Received 6 March 2021
Received in revised form 10 May 2021
Accepted 24 May 2021
Available online 5 June 2021

Keywords:
Decomposition
Decoupling
Environment
Sustainability
CO_2

ABSTRACT

The paper presents the environmental sustainability of the Nigeria transport sector (NTPS) through the decomposition and decoupling analysis from 1988–2019. The study's objective is to determine ways of saving energy in the NTPS and reduce carbon emission for a sustainable environment. The approach was based on the Logarithmic Mean Divisa Index (LMDI) and the Tapio approach, built on Kaya extended identity. Five decoupling indicators were considered based on the four energy carriers consumed in the NTPS. The indicators include economic activity, energy structure, economic structure, population and energy intensity. The results identified three decoupling states, weak negative decoupling, weak decoupling and strong decoupling. The energy intensity, economic activity, population and energy structure prevented decoupling during the study period, while the economic structure factor promoted decoupling. The overall impact of carbon emissions from NTPS was calculated at 44.45 million tonnes of CO_2. The study suggests frameworks that will support policy makers to formulate broad base policies for environmental sustainability.

1. Introduction

The demand for transport is increasing rapidly due to the growing demand for transportation by the other economic sectors: industry, energy, health, household, commercial etc. In 2016, the transport sector accounted for more than 24% of global CO_2 emissions (Wang and Ge, 2019). This trend is expected to grow at a faster rate, especially in emerging energy markets. Nigeria is a characteristic example of emerging global energy markets. The country's energy consumption structure is equally increasing in tandem with its socio-economic development. In 2017, its total energy consumption was estimated at 451.3 TWh, representing 0.26% of world energy consumption (NPEC, 2020). In 2018, the Nigeria transport sector (NTPS) GDP stood at 277 338.67 NGN million in the fourth quarter. The long-term was estimated to trend at about 244 302.00 NGN millions in 2020 from econometric models.

Conversely, the CO_2 emissions from the sector in 2014 were about 35.4% of the overall fuel consumption, with an increasing trend in recent times (NGDPT, 2020). Studies have shown that about 6.6 million vehicles in 2010 were listed plying the Nigerian highways. In 2015 and 2016, the vehicles were estimated to have increased to 9.8 and 10.6 million, respectively (VPN, 2020).

The NTPS comprises marine, railway, road and airway. The major energy carriers in these subsectors include oil, diesel, kerosene, and petrol. The road sector consumed about 90% of Premium Motor Spirit (PMS), also known as petrol, and 40% Automotive Gas Oil (AGO), also known as diesel, produced in the country. The aviation and water transport subsector consumed about 24% and 6% of the total Dual-Purpose Kerosene (DPK), also known as kerosene, and total AGO used in the sector, respectively (Oniwon, 2011). Statistics indicate that in 2019, Nigeria imported 20.8 billion litres of PMS, representing 57.2 million litres per day, while 5.15 billion litres of AGO was imported.

---

* Corresponding author.
E-mail address: abamfidelis@mouau.edu.ng (F.I. Abam).

https://doi.org/10.1016/j.egyr.2021.05.044

Similarly, the household kerosene, aviation turbine kerosene, low pour oil, and liquified petroleum gas imported stood at 128.11million litres, 1.07 billion litres, 45.98 and 526.06 million litres, respectively (NOC, 2021). Out of the 20.8 billion litres of imported PMS, over 80% is used by the land transport sector, excluding local production. Additionally, the increasing activities within the NTPS, mainly from the land transport subsector, proposes that the NTPS is significant in GHG emission inventories and a significant sector to be anticipated for mitigation potential.

From the global perspective, the carbon emissions were estimated at 32.4 Gt in 2014, which was increased by around 58% from the values in 1990. These values are disturbing since CO_2 is a key contributor to climate change and global warming. From the global CO_2 emissions, the transportation sector contributes about 21% of the total emissions (IEA, 2016). In 2010, the transportation sector emitted about 6.57 billion tonnes of CO_2 resulting from oil consumption alone (IEA, 2016). At present, the atmospheric CO_2 is estimated to at 400 ppm (IEA, 2017). It is projected to increase to about 530 and 650 ppm between 2050 and 2100, in that order. The latter is estimated to cause a rise in the middling global temperature between 2 and 5.6 °C by 2100. On the contrary, to tackle the current global warming challenge, the average temperature must exist below 2 °C (IEA, 2017; UNFCCC, 2015). This will require a cut down in CO_2 emission and a robust all-round policy by different economies of the world.

Furthermore, the contribution of the NTPS to the overall energy intensity between 1990 and 2011 was the highest, which stood at about 59% (Abam et al., 2014a). This value is projected to increase with time due to the increasing economic activities, with birth boom of vehicles, and population growth, which is currently estimated at approximately 202 million people (Okereke et al., 2021). Though the transport sector plays an important role in national development, it carries the burden of increasing global warming beyond the planet comfort level. Without concerted efforts and sustained ambition to reduce the transport sector's carbon emission, the transport sector could derail all the efforts to reduce carbon in the other energy-end use sectors. Therefore, it is necessary to understand the fundamental drivers of carbon emission in the transport sector and forge a pathway to reduce emission from the transport sector. In this regard, many researchers have attempted to decouple emission from the transport sector through decomposition analysis (Tapio, 2005; Jiang et al., 2018; Engo, 2019a,b).

Nigeria, in its Intended Nationally Determined Contributions (INDC) unconditionally, promised to cut down greenhouse gas (GHG) emissions by 20% in 2030 (INDC, 2014). To achieve this objective, the country intends to have a condensed energy mix structure and improve the entire energy efficiency by over 20%. One of the key measures to actualise this target apart from cutting down gas flaring by 45% in 2030 is improving the NTPS using efficient transport systems and eco-friendly energy carriers. Additionally, with the sustained increase in Nigerian transportation activities, coupled with economic and population growth, the proposed decarbonisation measures may be disrupted. Thus, it is imperative to advance an analytical or investigative framework to explore the CO_2 decoupling and identify the indicators that influence CO_2 emissions.

Several approaches exist in the literature for studying carbon emission trend in the transport sector. Some of the most applied approaches include system optimisation, input–output accounting, decomposition analysis, and econometric models. The econometric model's technique is widely used (Engo, 2019a,b). Pan et al. (2013) applied econometric and system optimisation techniques to determine the carbon emissions trend from France's transport sector. The findings show that road freight transportation contributed meaningfully to the increase in carbon emissions. Kim et al. (2009) presented a system optimisation technique to study the relationship between CO_2 emissions and freight transport in Europe. The results indicate the road sector's carbon intensity was much higher than the rail subsector. The input–output technique was applied by Wang and LI (2016) in 41 countries to appraise both downstream and upstream industries impact on carbon emissions. Three sectors from the studies: the extractive industries, the business and the manufacturing sectors, were identified as high indirect contributors to CO_2 emissions.

Scholars have widely applied the decomposition technique (Hasan and Chongbo, 2020). The technique exists in three components: the index decomposition analysis (IDA), theoretical decomposition analysis in production (PDA) and the structural decomposition analysis (SDA) (Zhang and Da, 2015). Among these techniques, the logarithmic mean divisa index (LMDI) within the IDA is mostly applied (Achour and Belloumi, 2016). The LMDI technique, which was formalised by Ang and Liu (2001), is widely applied to study the CO_2 emission trend from china's transport sector (Dai and Gao, 2016). Similarly, Andres and Padilla (2018) applied this method to understand the CO_2 trend in the Tunisia transport sector. The studies show that the population size, economic productivity, transport intensity, and transport structure, as regards the consumed energy, were positive, whereas energy intensity showed a negative effect. Edelenbosch et al. (2017) used the LMDI technique to investigate China's road transportation sector's key energy consumption indicators. Energy intensity and freight turnover were found to affect carbon emissions positively. Other applications of the technique can be found in Lopez et al. (2018), Jian (2015) and Mousavi et al. (2017). The growing popularity of the LMDI technique could be anchored on its simple and flexible theoretical foundation, ease of implementation, ease of computation, no residual term, accuracy, and straightforward result interpretation.

Furthermore, decoupling is an economic procedure for dissociating the relationship between the economic development terms and environmental pollution. Zhang (2000) first presented this in China to decouple China's CO_2 emissions from economic development. The decoupling concept supports materialisation and dematerialisation by establishing the delinking of environmental impairment from economic production (Yang et al., 2014; Becky and Banister, 2016). Many researchers have applied this method for countrywide analysis of CO_2. For example, Xiaoyu et al. (2018) presented transport CO_2 emissions and economic development in China. The study observed a weak decoupling relationship between carbon emissions transport and value-added. Tian et al. (2018) studied the decoupling between the Chinian transport sector's growth and the CO_2 emissions using the Tapio modified model. Engo (2018) combined the LMDI and Tapio methods to study the relationship between economic development and carbon emissions in the Republic of Cameroon. The country attained a weak decoupling, with the industrial sector having a negative decoupling trend. The application of Tapio's and LMDI was extended by Li et al. (2015) to study the decoupling relationship amongst energy-related carbon emissions and economic development in China. Also, Wang and Zhang (2021), applied Tapio's method to study the impact of trade openness on carbon emissions for 182 countries. The results show that trade openness positively impacts CO_2 decoupling from economic growth in developed economies and the contrary in poor economies. Other studies have extended Tapio's technique, as contained in the following literature (Chen et al., 2018; Román-Collado and Morales-Carrión, 2018; Engo, 2018; Wang and Ge, 2019; Wang and Su, 2020; Wang and Zhang, 2020).

Additionally, studies in Nigeria transport sector are very limited in this scope. For example, Badmus et al. (2012) presented the energy and exergy efficiency of the NTPS from 1990–2010, whereas Effiong et al. (2020) studied the sectorial contribution to CO_2 emissions in Nigeria economy from 2012–2027 using the

Intergovernmental Panel on Climate Change (IPCC) 2006 emission calculator default. The effect of energy intensity and economic structure on the energy consumption trend in three economic sectors of Nigeria: Industry, agriculture and transport, were presented by Abam and Effiom (2015). The study was based on a 3-D decomposition approach and generated very limited data for the transport sector. Maduekwe and Salisu Isihak (2020) evaluated the energy consumption and vehicular carbon emissions in Lagos using LEAP and the A–S–I (Avoid", "Shift", and "Improve") approaches. The results inferred that the decrease in road transport emissions in Lagos city is vehicle survivability sensitive. The study was limited since the entire country was not captured. Similarly, Dioha et al. (2021) presented alternate scenarios for low-carbon emissions in the Nigeria land transport sector based on a long-range energy alternative planning model. The alternative scenarios' carbon emissions were based on fuel substitution, and appropriate policy implications were recommended. Nonetheless, from the appraised literature very little information exist on the CO_2 decoupling from the NTPS to ascertain whether the carbon mitigation and transport enhancement capacity measures may be applied concurrently. The logarithmic mean Divisa index (LMDI) and Tapio approaches built on Kaya extended identity were applied in this study to narrow this gap and generate specific data in the Nigeria context for proper policy advancement. The latter was used to decouple, decompose, and evaluate the main drivers of carbon emissions from the NTPS, which define the study's objective and knowledge contribution. The decoupling pointers were subdivided into five different factors: energy intensity, energy structure, economic output, population, and economic structure. Similarly, the different energy carriers that powers the sub-transport sector were adequately covered in the study. It is further expected that the outcome of this study will serve as an evidential piece for policymakers to formulate articulated policies that support; energy efficiency and energy management, low-cost energy-end use and environmental sustainability.

2. Research methodology and data sources

In this study, we applied the econometric concept to analyse the NTPS. The Logarithmic Mean Divisa Index (LMDI) and the Tapio models built on an expanded Kaya identity was applied to decouple carbon emissions from energy consumption and their relationship with the economic indicators. Structured data from the records of the Nigeria Bureau of Statistics and published literature (NBS, 2020) and Badmus et al. (2012) were collected, which included the gross domestic product (GDP), demographic figures, and energy consumption in the respective subsectors. The three modes of transportation were covered alongside the fuel type utilised during the considered period. A 30-year data were collected covering the years from 1985 to 2019, as presented in Fig. A.1(a–d). The data analysis was considered from 1988–2019.

2.1. Models for approximating CO_2 emissions

Generally, two techniques are used in the transport sector for evaluating CO_2 emissions. These include the top-down (TPD) and the bottom-up (BUP) methods. In the BUP approach, the CO_2 emissions are evaluated based on the number of vehicles plying the road, energy consumed per kilometre covered for the various traffic categories, and the mileage. However, some researchers have noted that the BUP may introduce error due to the difficulty associated with the bottom-up data collection (Castesana and Puliafito, 2013). In the TPD, the emissions are estimated by multiplying the vehicular energy consumption with the fuel type's carbon emission factors (CEF). Thus, the TPD was adopted in this study according to Eq. (1) (Tapio, 2005).

Table 1
CO_2 emission factors for different fuel types.

Fuel type	FO	PMS	AGO	Aviation kerosene
Emissions tCO_2/GJ	0.074	0.0693	0.0741	0.07
Emissions tCO_2/PJ	73 600 000	6 990 000	67 400 000	69 600 000

Source: Tapio (2005).

$$\alpha = \sum_{i=1}^{n} \alpha_i^t = \sum_{i=1}^{n} F_i^t \times \delta_i \tag{1}$$

where α, α_i^t, F_i^t and δ_i, connotes the total (in ton) tCO_2 emission from NTPS, CO_2 emissions by type of fuel for the year t, the quantity of the fuel type i consumed during the year t, and carbon emission factor (CEF) of fuel type i. The CEF for the fuels used in the NTPS is depicted in Table 1

2.2. Logarithmic Mean Divisia Index Method (LMDI)

From the index decomposition analysis, if V is an aggregate composed of n factors $(x_1, x_2, \ldots .x_n)$ such that from period 0 to T the aggregate changes from V^0 to V^T, then

$$V = \sum_i V_i \tag{2}$$

where $V_i = x_{1,i}, x_{2,i}, \ldots, x_{n,i}$

The contributions of the n factors to the change in the aggregate can be expressed as (Ang and Liu, 2001):

$$\Delta V_{total} = V^T - V^0 = \Delta V_{x1} + \Delta V_{x2} + \cdots + \Delta V_{xn} \tag{3}$$

Thus, the general expression for the LMDI method is expressed as (Ang, 2005):

$$\Delta V_{xk} = \sum_i L\left(V_{i,}{}^T V_i^0\right) ln\left(\frac{x_{k,i}{}^T}{x_{k,i}{}^0}\right) \tag{4}$$

The logarithmic mean of the aggregate V is expressed with the following relationship (Ang, 2005)

$$L\left(V_{i,}{}^T V_i^0\right) = \frac{V_{i,}{}^T - V_{i,}{}^0}{\ln\left(V_{i,}{}^T\right) - \ln(V_{i,}{}^0)} \tag{5}$$

The relative contribution of the terms which constitutes the effects of energy decomposition is expressed with the LMDI method with the relationships expressed in (Ang, 2005):

$$\Delta E_{activity} = \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]}\right) ln\left[\frac{I_i{}^T}{I_i{}^0}\right] \tag{6}$$

$$\Delta E_{intensity} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]}\right) ln\left[\frac{s_i{}^T}{s_i{}^0}\right] \tag{7}$$

$$\Delta E_{structure} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]}\right) ln\left[\frac{A_i{}^T}{A_i{}^0}\right] \tag{8}$$

where: I, S and A represents economic activity, energy intensity and energy structure respectively. Note: the nomenclature used for the indicators are at authors discretion for convenience of uniformity as used in subsequent sections.

The development of the LMDI method is based on Eq. (2), which is expressed in terms of the energy consumption as:

$$\Delta E_{total} = E^T - E^0 = \Delta E_{x1} + \Delta E_{x2} + \cdots + \Delta E_{xn} \tag{9}$$

The expression in Eq. (9) can be altered to the form:

$$\Delta E_{total} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]} \right) ln \left[\frac{E_i{}^T}{E_i{}^0} \right] \tag{10}$$

By substituting terms of energy consumption and following the nomenclature of the current and reference years, the following expression is obtained:

$$\Delta E_{total} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]} \right) ln \left[\frac{\beta^T S_i{}^T I_i{}^T}{\beta^0 S_i{}^0 I_i{}^0} \right] \tag{11}$$

Expanding the natural logarithm term in Eq. (11), the following expression is obtained:

$$\Delta E_{total} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]} \right) \times \left(ln \left[\frac{\beta_i{}^T}{\beta_i{}^0} \right] + ln \left[\frac{S_i{}^T}{S_i{}^0} \right] + ln \left[\frac{I_i{}^T}{I_i{}^0} \right] \right) \tag{12}$$

By expanding Eq. (12):

$$\begin{aligned} \Delta E_{total} = & \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]} \right) ln \left[\frac{\beta_i{}^T}{\beta_i{}^0} \right] \\ & + \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]} \right) ln \left[\frac{S_i{}^T}{S_i{}^0} \right] \\ & + \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln\left[E_i{}^T\right] - ln\left[E_i{}^0\right]} \right) ln \left[\frac{I_i{}^T}{I_i{}^0} \right] \end{aligned} \tag{13}$$

where:
β is the total GDP of the country; β_i is the GDP generated by the ith sector; E_i is the energy consumption in the ith sector; S_i is the structure for ith sector; I_i is the energy intensity in the ith sector.

2.3. CO_2 emissions decoupling from the LMDI

The empirical model required to calculate the quantity of CO_2 emissions from fossil energy is presented by quantifying the contributions of five different factors: scale of the economy, transport sector activity mix, sector energy intensity, sector energy mix, and emission values factors. Additionally, different sub-categories are considered concerning the transport sectors and fuel type. The carbon dioxide emissions can be written as (Robalino et al., 2014)

$$\alpha = \sum_{ij} \alpha_{ij} = \beta \sum_{ij} \frac{\beta_i}{\beta} \frac{E_i}{\beta_i} \frac{E_{ij}}{E_i} \frac{\alpha_{ij}}{E_{ij}} = \beta \sum_{ij} S_i \times I_i \times M_{ij} \times F_{ij} \tag{14}$$

where:
α, is the total carbon dioxide emissions for the whole sector in a given year; α_{ij} is the total carbon dioxide emissions arising from fuel type j in the ith sector; E_{ij} is the energy due to consumption of fuel j in the ith sector; M_{ij} is the energy matrix expressed for the ith sector as the energy from fuel type j to the total energy in the sector; F_{ij} is the carbon dioxide emission factor for the ith sector.

Following the methods for the LMDI analysis, Eq. (14) can be written as follows (Ang, 2005; Wang et al., 2018)

$$\Delta\alpha_{total} = V^T - V^0 = \Delta C_{activity} + \Delta C_{structure} + \Delta C_{intensity} + \Delta C_{mix} + \Delta V_F \tag{15}$$

where each of the terms in Eq. (15) is expressed as:

$$\Delta\alpha_{activity} = \sum_i \left(\frac{\alpha_{ij}{}^T - \alpha_{ij}{}^0}{ln\left[\alpha_{ij}{}^T\right] - ln\left[\alpha_{ij}{}^0\right]} \right) ln \left[\frac{I^T}{I^0} \right] \tag{16}$$

$$\Delta\alpha_{structure} = \sum_i \left(\frac{\alpha_{ij}{}^T - \alpha_{ij}{}^0}{ln\left[\alpha_{ij}{}^T\right] - ln\left[\alpha_{ij}{}^0\right]} \right) ln \left[\frac{A_i{}^T}{A_i{}^0} \right] \tag{17}$$

$$\Delta\alpha_{intensity} = \sum_i \left(\frac{\alpha_{ij}{}^T - \alpha_{ij}{}^0}{ln\left[\alpha_{ij}{}^T\right] - ln\left[\alpha_{ij}{}^0\right]} \right) ln \left[\frac{S_i{}^T}{S_i{}^0} \right] \tag{18}$$

$$\Delta\alpha_{mix} = \sum_i \left(\frac{\alpha_{ij}{}^T - \alpha_{ij}{}^0}{ln\left[\alpha_{ij}{}^T\right] - ln\left[\alpha_{ij}{}^0\right]} \right) ln \left[\frac{M_{ij}{}^T}{M_{ij}{}^0} \right] \tag{19}$$

$$\Delta\alpha_{F} = \sum_i \left(\frac{\alpha_{ij}{}^T - \alpha_{ij}{}^0}{ln\left[\alpha_{ij}{}^T\right] - ln\left[\alpha_{ij}{}^0\right]} \right) ln \left[\frac{F_{ij}{}^T}{F_{ij}{}^0} \right] \tag{20}$$

2.4. Decomposition and decoupling estimation from Tapio's and Kaya's extended models

Tapio's decoupling technique, an elastic procedure, was first proposed by Tapio, who applied this method in decoupling standards for the European transport capacities and carbon emission from the year 1970–2001 (Tapio, 2005). Tapio's decoupling model utilises the flexibility index to analyse the decoupling link between economic development and environmental concerns, which is expressed as follows (Tapio, 2005):

$$D_{(\alpha,\beta)} = \frac{\frac{\Delta\alpha}{\alpha}}{\frac{\Delta\beta}{\beta}} \tag{21}$$

where the terms, $D_{(\alpha,\beta)}$, $\%\Delta\alpha$, $\%\Delta\beta$ denotes, decoupling index (DI) of carbon emissions (α) and GDP (β), percentage variations in CO_2 and GDP in that order. The study (Tapio, 2005) presented eight logical probabilities in which the decoupling state between economic advancement for a sector and its environmental complications is based, as presented in Table 2.

The Kaya's identity, is an adapted form of IPAT identity, first presented by Ehrlich and Holdren (1971). In Kaya's model, the carbon emissions are expressed as a function of four factors: population, gross domestic product (GDP) per capita, carbon intensity, GDP and energy intensity. The general expression is presented in Eq. (22) (Kaya, 1990).

$$\alpha = P \times \frac{\alpha}{E} \times \frac{E}{\beta} \times \frac{\beta}{P} \tag{22}$$

where α, β, E, and P, connotes carbon emissions, GDP, energy consumption and population. The carbon intensity of the NTPS was disintegrated into six factors to give the expression in Eq. (23).

$$\alpha = \sum_i^n \frac{\alpha_i}{E_i} \times \frac{E_i}{E} \times \frac{E}{\beta_i} \times \frac{\beta_i}{\beta} \times \frac{\beta}{P} \times P = f \times A \times S \times Q \times I \times P \tag{23}$$

where α, (α_i), and (E_i) denotes carbon intensity, the carbon emitted from fuel i, the total quantity of fuel consumed by type i and the added value of the NTPS, respectively. Furthermore, f, A, S, Q, I, P represents emission factor, energy structure, energy intensity, economic structure, economic activity and population. Employing the LMDI additive method presented by Ang (2005), the change in CO_2 between the base year (0) and an anticipated year (t) was described from Eq. (24) as:

$$\Delta\alpha_{total} = \alpha^1 - \alpha^0 = \Delta\alpha_f + \Delta\alpha_A + \Delta\alpha_S + \Delta\alpha_Q + \Delta\alpha_I + \Delta\alpha_P \tag{24}$$

$$\Delta\alpha_f = \sum_{i=1}^n W(\alpha_i^t, \alpha_i^0) \times ln \left(\frac{f_i^t}{f_i^0} \right) \tag{25}$$

$$\Delta\alpha = \sum_{i=1}^n W(\alpha_i^t, \alpha_i^0) \times ln \left(\frac{A_i^t}{A_i^0} \right) \tag{26}$$

Table 2
The logical conditions for describing decoupling status.
Source: Tapio (2005).

S/N	Decoupling status	$D_{(\alpha,\beta)}$	$\%\Delta\alpha$	$\%\Delta\beta$
1	Strong decoupling	$D_{\alpha,\beta} < 0$	< 0	> 0
2	Weak decoupling	$0.8 \geq D_{\alpha,\beta} > 0$	> 0	> 0
3	Recessive coupling	$1.2 \geq D_{\alpha,\beta} > 0.8$	< 0	< 0
4	Expansive negative decoupling	$D_{\alpha,\beta} > 1.2$	> 0	> 0
5	Strong negative decoupling	$D_{\alpha,\beta} < 0$	> 0	< 0
6	Weak negative decoupling	$0.8 \geq D_{\alpha,\beta} > 0$	< 0	< 0
7	Expansive decoupling	$1.2 \geq D_{\alpha,\beta} > 0.8$	> 0	> 0
8	Recessive decoupling	$D_{\alpha,\beta} > 1.2$	< 0	< 0

$$\Delta\alpha_S = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{S_i^t}{S_i^0}\right) \tag{27}$$

$$\Delta\alpha_Q = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{Q_i^t}{Q_i^0}\right) \tag{28}$$

$$\Delta\alpha = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{I_i^t}{I_i^0}\right) \tag{29}$$

$$\Delta\alpha_P = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{P_i^t}{P_i^0}\right) \tag{30}$$

where $W(\alpha_i^t, \alpha_i^0) = \frac{\alpha_i^t - \alpha_i^0}{ln\alpha_i^t - ln\alpha_i^0}$ is the weight function defined as follows

$$W\,(a, b) = \begin{cases} aa = b \\ 0a = b = 0 \\ \dfrac{a-b}{ln\left(\frac{a}{0}\right)} \quad a \neq b \end{cases} \tag{31}$$

From Eq. (25), since the carbon emission factor of the different energy carriers is constant, it implies that $\alpha_f = 0$, consequently, the carbon emissions from the NTPS were influenced by the transformation in the energy structure. However, to define the decoupling pointers from the Tapio model, Eq. (24) is integrated into Eq. (21) to get the following equations:

$$D(_{\alpha,\beta}) = \frac{\beta}{\alpha \times \Delta\beta} \times \left(\Delta\alpha_f + \Delta\alpha_A + \Delta\alpha_S + \Delta\alpha_Q + \Delta\alpha_I + \Delta\alpha_P\right) \tag{32}$$

$$D(_{\alpha,\beta}) = Df + DA + DS + DQ + DI + DP \tag{33}$$

$$Df = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{f_i^t}{f_i^0}\right) \times \frac{\beta}{\alpha \times \Delta\beta} \tag{34}$$

$$DA = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{A_i^t}{A_i^0}\right) \times \frac{\beta}{\alpha \times \Delta\beta} \tag{35}$$

$$DS = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{S_i^t}{S_i^0}\right) \times \frac{\beta}{\alpha \times \Delta\beta} \tag{36}$$

$$DQ = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{Q_i^t}{Q_i^0}\right) \times \frac{\beta}{\alpha \times \Delta\beta} \tag{37}$$

$$DI = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{I_i^t}{I_i^0}\right) \times \frac{\beta}{\alpha \times \Delta\beta} \tag{38}$$

$$DP = \sum_{i=1}^{n} W(\alpha_i^t, \alpha_i^0) \times ln\left(\frac{P_i^t}{P_i^0}\right) \times \frac{\beta}{\alpha \times \Delta\beta} \tag{39}$$

2.5. Comparison of CO_2 emission drivers in the transport sectors of selected countries

The current study was compared with decomposition analysis of CO_2 emission from the transport sector of selected countries. For Nigeria, Energy intensity, energy structure, economic activity and population were the major drivers that hindered CO_2 reduction in the transport sector. However, some of these factors where common in the developing economies as shown in Table 3.

3. Results and discussion

3.1. Decoupling indicators of Nigerian's transport sector

In this research work, it was observed that the overall cumulative decoupling value index ($D_{\alpha,\beta}$) between the energy-associated CO_2 emissions in addition to the transport sector's development existed at −18.453 in real value (see Table B.1). The economic term (β) showed positive growth, whereas the environmental indicator (α) showed negative growth. This implies that the NTPS attained a strong decoupling between the energy-associated carbon emissions and the transport sector growth throughout 1988–2019. Additionally, all through this period, the results show that the carbon emissions increase at some periods with the transport sector's growth, showing a low growth rate than transportation value additions, consequently reflecting enhancement in the sector's energy intensity (see Fig. 1). Furthermore, from 1988–2019 (see Table C.1), five decoupling states occurred, which defines the relationship between energy-related CO_2 emissions and the growth in the NTPS. These include (i) weak negative decoupling, (ii) weak decoupling (iii) strong decoupling.

3.2. Weak negative decoupling

The weak negative decoupling occurred during 1989–1990, 1990–1991, 1991–1992. Similarly, a weak decoupling occurred during 1993–1994, 1994–1995, 1995–1996, 2000–2001, 2001–2002, and 2002–2003, whereas the following periods, 2003–2004, 2004–2005, 2005–2006, 2006–2007, 2009–2010, 2010–2011, 2011–2012, and 2012–2013 attained a strong decoupling. Though, the weak negative decoupling state from the NPTS suggests that despite the declining profile of CO_2 and the transportation sector growth, the reduction in CO_2 emissions was still less when compared with the extent of the economic "go-slow". Though, this was found to have been responsible for the slight growth in the sector's energy intensity. It can be inferred that the economic crisis of the 1980s must have resulted in the negative economic trend from 1987–1992 and the reduction in oil production.

3.3. Weak decoupling

The second status of decoupling (weak decoupling) shows that the value-added growth in the NTPS was faster than the CO_2 emissions, still reflecting a high environmental and energy expenditure slightly. The value-added in the NTPS stood at 3.85% in 1994, 6.14% in 1995 and 7.14% in 1996 (Fig. 1). This was ascribed to the following: Federal government policy on the transport sector reforms between 1980 and 1990s, including the establishment of the Urban mass transit Agency (FUTMA) and the Petroleum Trust fund (PTF). The duo triggered the government to allocate enormous investment in the NTPS between 1990–1999, progressing the plan period and increase workers engagement in NTPS and consequently increased sector GDP (NTP, 1993; Ugboaja and Ukpere, 2011). Additionally, the rehabilitation and construction of the major Federal highways in the 1995 countrywide network contributed to improving the energy intensity and reducing carbon emissions.

Table 3
Comparison of emission drivers in the transport sectors of some selected countries.

S/No	Country	Studies	CO_2 emission drivers	Reference
1	Philippines	Decomposing drivers of transportation energy consumption and carbon dioxide emissions for the Philippines: the case of developing countries	Energy intensity, transport activity and population growth	Lopez et al. (2018)
2	Cameroon	Decoupling analysis of CO_2 emissions from transport sector in Cameroon	Scale effect, energy structure effect and energy intensity	Engo (2019a,b)
3	China	Decomposition analysis of energy-related carbon emissions from the transportation sector in Beijing	Economic growth, energy intensity and population growth	Fan and Lei (2016)
4	India	Factorising the Changes in CO_2 emissions from Indian road passenger transport: A decomposition analysis	Economic growth, transport activity and population	Gupta and Sing (2016)
5	Bangladesh	Decomposition study of energy-related CO_2 emissions from Bangladesh's transport sector development	Economic activity, population, economic structure and energy intensity.	Hossain et al. (2020)
6	Tunisia	Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method	Energy intensity, economic activity transport structure, transportation intensity, and population.	Achour and Belloumi (2016)
7	Nigeria	Environmental sustainability of the Nigeria transport sector through decomposition and decoupling analysis: With the future framework for sustainable transport pathways	Energy intensity, energy structure, economic activity and population	Current studies

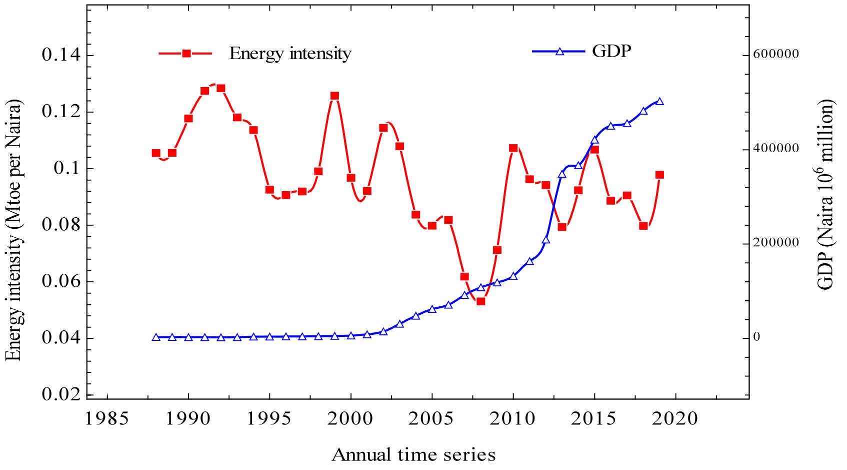

Fig. 1. Trends in Nigerian's GDP and energy intensity from the transportation sector during 1988–2019.
Source: Author's calculation.

3.4. Strong decoupling

The periods of strong economic decoupling are from 2003–2006 and 2008–2013. This shows that the NTPS had a positive increase in growth. In contrast, carbon emissions decreased, showing an improvement in energy consumption and eco-friendly quality. Overall, Nigeria's GDP at 1990 basic constant prices grew by 24.71% between 2003 and 2007 with an annual increase of about 6.56%. In a comparable vein, the GDP of the NTPS increased by 22% between 2003 and 2007. It contributed about 2.68% to the overall GDP (CBN, 2007; NBS, 2008). From Table C.1, weak decoupling states existed in most periods, indicating that the carbon emissions and the growth in the NTPS are in tandem. Though, these periods also indicate the Nigerian government efforts to improve the transport sector following resource utilisation and the environment. In the same vein, the government is not consistent with the policy implementation in the NTPS as it indicates clearly in other periods. Most vehicles in Nigeria, especially in the road transport sector, are not at the cutting-edge technology. For this reason, there is energy consumption increase by the automobiles in the road transport sector. Nevertheless, it is required for the government to concentrate its efforts on new cutting-edge technologies and strategies connected to modern transport models. Consequently, the Nigerian government should also encourage research and development in all facets of her institutions, provide a good research environment to fast-track new technologies for sustainable growth in the transport sector.

3.5. Decomposition breakdown of the decoupling components from the NTPS

3.5.1. Carbon emissions effect factor

The total annual time series of CO_2 emission decomposition in (tCO_2) for the NPTS is presented in Table C.1. The overall impact of carbon emissions from NTPS was calculated at $4.9E{-}05$ tCO_2 which corresponded to a 163% increase in the overall country's CO_2 emissions during 1988–2019. From Fig. 2, it can be inferred that the overall effect of the carbon emissions was nearly positive and continual over the considered period of study. However, the latter made it probable to separate it to some extent from the transport sector's growth, as depicted in Table C.1 and Fig. 3.

3.5.2. Population effect factor

The cumulative effect of the population factor is about 33.91 million tonnes of CO_2, equivalent to a 97.95% rise in the overall CO_2 emissions observed from the NTPS during the study period,

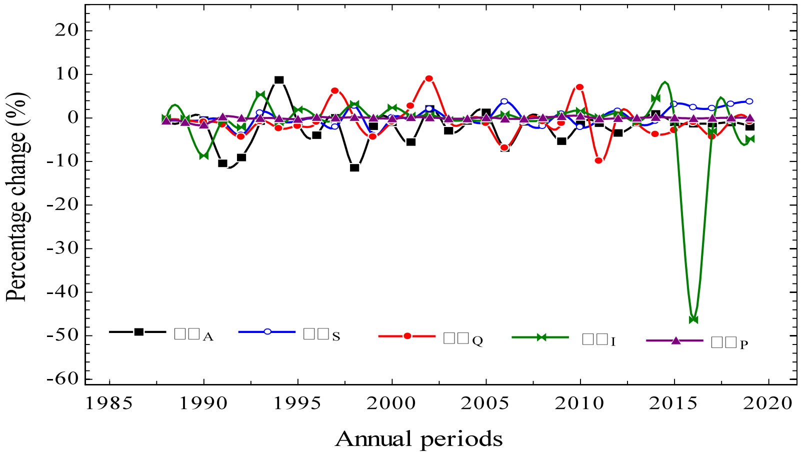

Fig. 2. Total CO_2 emission decomposition from NTPS from 1988–2019.
Source: Author.

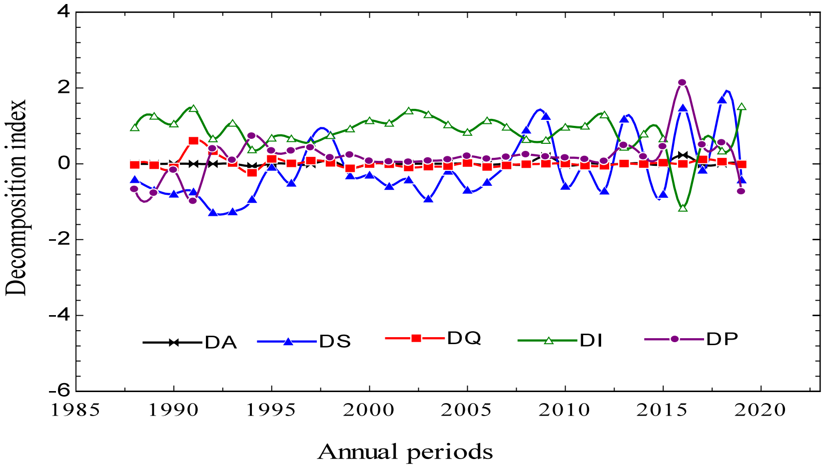

Fig. 3. Annual decomposition of the decoupling indicators in the NTPS from 1988–2019.
Source: Author.

1988–2019. The study also shows that the demographic factor added to the CO_2 emission increase during this period (Fig. 2), preventing the complete decoupling between the CO_2 emissions and the sector's growth, as depicted in Fig. 3. The reasons are ascribed to the following: (i) the fast-growing population rate in Nigeria, which grew from 90,395,271 in 1988 to 200, 963, 595 in 2019 (about 55.02%), and the Urbanisation growth rate, which increased from 5.4% in 1988 to 51.6% in 2019 (NPAUR, 2021). The above has undoubtedly increased needs such as energy and transportation, thus increasing CO_2 emissions.

3.5.3. Economic activity effect factor

The economic activity's effect is estimated at 1.09 million tonnes of CO_2, which correspond to an approximately 72% growth increase in the overall CO_2 emissions from the NTPS (Table C.1). The economic activity effect from Fig. 3 shows that it prevented decoupling in the considered study period. Similarly, Fig. 2 indicated that the activity effect increased unevenly and contributed to dipping CO_2 emissions to about 30%, thus reducing the decoupling index. However, during this study period, economic growth improved from −5.75% in 1988 to 11.45% in 2019. The country's GDP/capita grew from 549 to 2,230 at constant 2010 USD in the same vein.

Conversely, apart from the following years 1989–1990, 1993–1998, 2000–2003 and 2009–2012, where the upshot of the economic activity resulted in CO_2 emissions decrease, it is clear from Fig. 3 that the upshot of the economic activity was constant and also increasing throughout the period. This improvement was mirrored in the population's social lifestyle, culminating in acquiring more private and commercial vehicles. Since the demand for the populace's basic life necessities was increased sequel to enhancing the living standard, Nigeria's entire logistics network continued to depend largely on conventional fuel-powered by the sector. Nevertheless, this was responsible for the concurrent CO_2 emissions increase and the weak decoupling state's attainment. Consequently, policy should be directed towards decreasing the economic progress rate and advancing the value of economic growth in general with specific attention to the transportation sector.

3.5.4. Energy structure effect factor

The overall cumulative impact of the energy structure was calculated at 8.85 million tonnes of CO_2, equivalent to about 89.78% growth rate of the overall CO_2 emissions in the NTPS for the study period 1988–2019. The result connotes that the energy structure impact played a major role in deterring carbon emission decoupling from the transport sector growth from 1988–2019

(Fig. 3). In Nigeria, the road transport subsector is the most energy-intensive since it accommodates to a large extent the transport requirements of the population. With this, the transport subsector remains the highest emitter of carbon emissions. Currently, Nigeria has an approximately 195,000 km road network, in which 32,000 km belong to the federal category.

In comparison, 31,000 km belong to the state category, out of which only near 60,000 km are paved. In 2015 and 2016, the country's vehicle fleet increased from 9.8 to 10.6 million, respectively (VPN, 2020). Thus, this circumstance could rationalise the increase in energy utilisation attained in the NTPS throughout the study, as depicted in Fig. A.1. Also, from Fig. A.1, it is observed that the premium motor spirit (PMS) and automotive diesel oil (AGO), which are high emitters of CO_2, were much consumed. On this note, it can be concluded that the energy structure impact contributed to the dipping of CO_2 emissions on periods where their utilisation was minimal. It is, however, required that policy should be directed towards regulating energy consumption in the transport sector, as this effect emanates from the variations in the energy structure of the sector.

3.5.5. *Energy intensity effect factor*

The overall cumulative effect of the energy intensity is 14.60 million tonnes of CO_2, which correspond to a show that from Fig. 3, the energy intensity helped prevent decoupling during the study period, while bout a 75.51% increase of the total carbon emissions in the NTPS for 1988–2019. The result Fig. 2 indicates that this factor's impact grows unevenly and added to dipping CO_2 emissions for approximately 30% during the study stages, which likewise abridged the index of decoupling. The slight decrease in CO_2 emissions by this factor could be attributed to the marginal decline in the different fuel consumption types. The cars in Nigeria were ageing, and their design not in tandem with modern transport technology. However, since the major indices for energy intensity reduction are technological advancements, policy on the technology to support energy saving is ideal. Adopting standards for particular fuel consumption types for transport vehicles and new transport cars, either hydrogen or electric-powered, will be adequate.

3.5.6. *Economic structure effect*

The economic structure's overall effect is estimated at −19.96 million tonnes of CO_2, translating to about −70.3% in real terms indicating that the economic structure effect contributed to reducing the overall CO_2 emissions from the NTPS period 1988–2019 (Table C.1). Also, Fig. 3 shows that the economic structure effect played a significant part in the decoupling trends. Similarly, Fig. 1 shows that the value-added increased positively during the study period, opposite to energy intensity increase, which implies improvement in the sector's efficiency. From 1989 to the 1990s, the government has made efforts to reform the transport sector by improving service quality to include the transport sector's stability, capacity, and efficiency. Additionally, the major road network rehabilitation and the establishment and reorganisation of the energy supply chain culminated in establishing petroleum products deports that improved the NTPS and led to CO_2 emissions reduction.

4. Conclusion and future framework for sustainable transport pathways

The econometric based extended approach (EMAP) was applied in this study. In the EMAP, the Log-Mean Divisa Index (LMID) and the Tapio models built on an expanded Kaya identity was applied to decouple carbon emissions from the NTPS from 1988–2019. Four major fuels utilised in the NTPS, AGO, PMS, FO AVK ware considered while the decoupling pointers were split into five factors, which comprises: population, economic structure, economic activity, energy intensity and energy structure. The observed results from the study are summarised as follows: The overall impact of carbon emissions from NTPS was estimated at 44.45 million tonnes of CO_2 which correspond to the 163% increase in the overall country's carbon emissions during 1988–2019. Though the carbon emission growth rate was in tandem with the transport sector growth lower than the added value of the NTPS; consequently, a weak decoupling state existed in the correlation between energy-associated carbon emissions and the NTPS growth. The following periods 1989–1990, 1990–1991, 1991–1992, experience a weak negative decoupling. Likewise, a weak decoupling occurred during 1993–1994, 1994–1995, 1995–1996, 2000–2001, 2001–2002, and 2002–2003, whereas the following periods, 2003–2004, 2004–2005, 2005–2006, 2006–2007, 2009–2010, 2010–2011, 2011–2012, and 2012–2013 attained a strong decoupling. The economic structure's overall effect is estimated at -19.96 million tonnes of CO_2, which correspond to about −70.3% in actual terms signifying that the economic structure effect contributed to dipping the overall CO_2 emissions from the NTPS during the period 1988–2019. However, the population growth rate from the study was the major driver of carbon emissions in the NTPS, followed by energy structure with about (89.78%), energy intensity (75.51%) and economic activity (72%). The energy structure effect and the energy intensity effect assumed negative at some years within the study periods. The conclusive results indicate that the economic structural factor was the only indicator that contributed to dipping carbon emissions from the NTPS during 1988–2019.

Following the findings from this study, the authors observed the succeeding policy suggestions are imperative to define the carbon emission mitigation strategies in the Nigerian transport sector.

(i) Indicators from the study show that Nigeria's transport sector's efficiency needs to be improved through a well-defined optimisation approach. The study shows that energy intensity plays a role in dipping CO_2 during about 30% of the study period, attributed to the marginal decline in some grade of fuel in the energy supply chain of the NTPS. Nonetheless, this proposes that the energy intensity and energy structure effects are significant pointers for energy efficiency improvement in the NTPS. Consequently, the Nigerian government should focus on developing low carbon-intensive energy carries, such as biofuel and fuel cell vehicles. The conventional energy consumption in the NTPS is predominantly PMS and AGO, which dominates the road transport sector and constitute about 65% of the total energy consumed in the NTPS. The PMS and AGO have a high depletion rate, high exergy waste ratio and low exergy efficiency. On this note, a condensed energy mix structure is recommended to develop new energy sources for the transport sector through the vast potential of Nigeria's underutilised renewable energy. Furthermore, phasing out CO_2 intensive automobiles from the road traffic is required. Also, removing fuel suicides to allow for actual taxes and prices adjustment of conventional automobile fuels will stabilise and reduce purchasing power.

(ii) The economic structure effect was the major driver in dipping CO_2 emission from the NTPS, which led to an increase in the sector's exergetic efficiency and environmental sustainability improvement. This improvement is tied to quality infrastructures such as good road network, quality of automobiles, quality of service, and energy carriers. The Nigerian government should upgrade the road network;

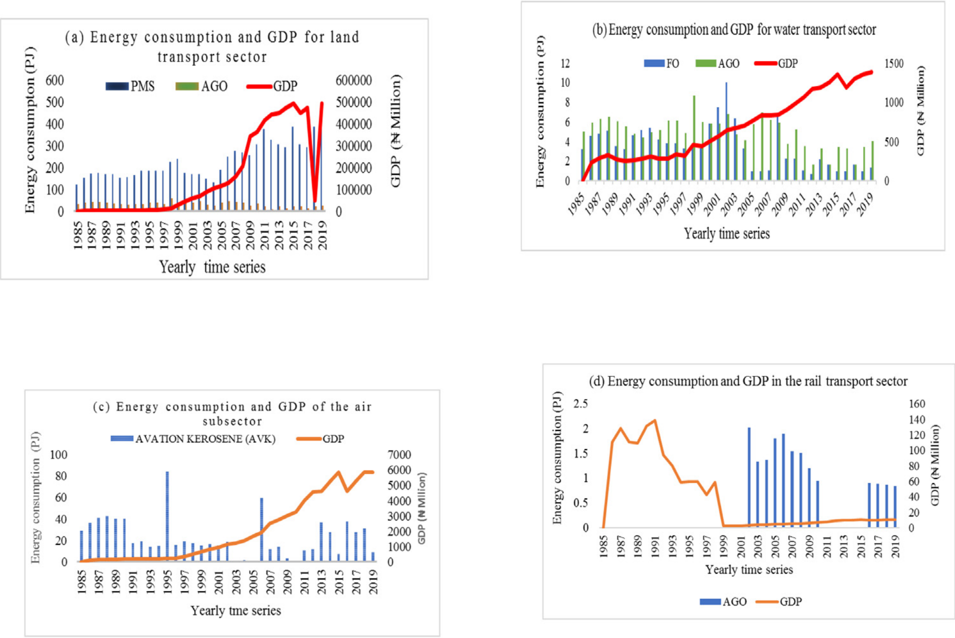

Fig. A.1. Historical energy consumption in the transport subsectors from 1985–2019 (a) land (b) Water (c) Air and (d) Rail.

only about 45% of the Federal roads are paved. Also, about 70% of the car fleet in the NTPS are ''TOKUMBO'', a local term used to describe fairly used cars. These cars have reduced efficiency as their parts are almost or close to their duty cycles. Thus, resulting in high entropy generation during energy conversion processes which lead to high CO_2 emissions. The development of new automobiles in the sector to run on low carbon fuel will reduce environmental depletion rate and improve the sector overall exergetic efficiency

(iii) The demographic effect contributed to a 97% increase in CO_2 emission during the study period in the NTPS. Population growth implies an increase in basic needs, both energy and economic necessities. Therefore, population growth and economic activity must be controlled since they influence the increase of CO_2 emission from the study. An effective birth control programme, adequate orientation or sensitisation on the low-carbon transport system, and eco-friendly safety responsiveness are imperative.

(iv) The Nigeria government should generally improve the quality of transport infrastructure from land, air, water and rail. They should be a strong drive from the government to lift and encourage the public transport system in the NTPS instead of the private transport system's current domination. Also, narrow the capacity gap for transport infrastructural development, operation, management and maintenance.

(v) The establishment of special transport institutes in the country is important for high-capacity development. Institutional Research should focus on new cutting-edge technologies across all facet of the transport subsectors. The development of new transport models: (i) to handle the growing population's transport needs and (ii) the urbanisation trend identified in this study as a major driver to increased needs (mostly in energy demand).

(vi) The transport standards in the NTPS should be developed. As a point of innovation, the government should invest in developing and improving the transport sector standards. For instance, a policy permitting the phase-out of two strokes cycle motorbikes as a transport system and phasing out old models' vehicles with poor combustion efficiency is imperative. Additionally, an implementation of up-to-date or informed fuel standards (e.g., Euro standards) is noteworthy in tandem with global practice in terms of clean fuel and environmental initiatives.

CRediT authorship contribution statement

Fidelis I. Abam: Developed the idea. **Ekwe B. Ekwe:** Developed models, Manuscript write up. **Ogheneruona E. Diemuodeke:** Equally developed models. **Michael I. Ofem:** Data analysis. **Bassey B. Okon:** Manuscript development. **Chukwuma H. Kadurumba:** Manuscript development. **Archibong Archibong-Eso:** Data analysis. **Samuel O. Effiom:** Data analysis. **Jerome G. Egbe:** Manuscript organization, Data analysis. **Wisdom E. Ukueje:** Model development.

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

See Fig. A.1.

Appendix B

See Table B.1.

Appendix C

See Table C.1.

Table B.1
Estimated CO_2 emissions decoupling indicators from the Nigerian's transportation sector during the period 1988–2019.

Year	$\%\Delta\alpha$	$\%\Delta\beta$	$D_{(\alpha,\beta)}$	Decoupling state
1988–1989	−0.20805	−0.90133	−8.54536	Weak negative decoupling
1989–1990	−0.35944	−0.02194	−0.80491	Weak negative decoupling
1990–1991	−0.66235	−0.10964	−3.14811	Weak negative decoupling
1991–1992	−2.72674	−0.01021	−0.88955	Weak negative decoupling
1992–1993	−0.71246	0.07187	−0.06592	Strong decoupling
1993–1994	8.50356	0.36875	−5.12016	Weak decoupling
1994–1995	1.02386	0.04020	0.07235	Weak decoupling
1995–1996	7.13545	0.06548	0.51761	Weak decoupling
1996–1997	1.80936	0.07686	1.67312	weak decoupling
1997–1998	2.26022	0.05907	1.79178	weak decoupling
1998–1999	−1.91567	0.15064	−2.36728	Strong decoupling
1999–2000	−0.91259	0.13022	−0.07942	Strong decoupling
2000–2001	12.09487	0.47366	0.53698	Weak decoupling
2001–2002	−1.15547	0.66515	−0.06853	Strong decoupling
2002–2003	4.84932	1.12356	−0.70024	Weak decoupling
2003–2004	−0.91225	0.55179	−0.09751	Strong decoupling
2004–2005	−3.31788	0.29385	−0.38624	Strong decoupling
2005–2006	−5.58493	0.15011	−1.32651	Strong decoupling
2006–2007	−0.59425	0.28688	−0.90208	Strong decoupling
2007–2008	3.81936	0.17759	3.13636	Weak decoupling
2008–2009	0.98488	0.09654	3.37214	Weak decoupling
2009–2010	−1.23123	0.11739	−0.47213	Strong decoupling
2010–2011	−1.06572	0.23614	−0.02902	Strong decoupling
2011–2012	−24.45971	0.27745	−0.40239	Strong decoupling
2012–2013	−2.23238	0.66475	−3.33828	Strong decoupling
2013–2014	0.12979	0.05171	1.19815	Weak decoupling
2014–2015	−1.94012	0.14843	−2.65921	Strong decoupling
2015–2016	−1.29540	0.06979	4.18613	Weak decoupling
2016–2017	−3.00606	0.01200	−1.99610	Strong decoupling
2017–2018	−3.36040	0.05757	4.96331	Weak decoupling
2018–2019	0.23705	0.04265	−7.54648	Weak decoupling

Table C.1
Total annual time series CO_2 emission decomposition in (million tonnes of CO_2) for the Nigerian transport sector 1988–2019.

Year	$\Delta \propto_A$	$\Delta \propto_S$	$\Delta \propto_Q$	$\Delta \propto_I$	$\Delta \propto_P$	$\Delta \propto_{total}$
1988–1989	0.298	0.91	−33.92	3.57	0.82	−28.30
1989–1990	−0.159	331.10	19.59	−217.70	33.65	166.00
1990–1991	0.019	84.260	−10.88	−61.68	44.26	56.05
1991–1992	−0.383	−249.40	36.37	72.65	43.72	−97.05
1992–1993	−0.102	−543.30	8.607	464.40	42.08	−27.84
1993–1994	−3.175	−306.60	−12.24	19.50	38.00	−2639.00
1994–1995	0.277	−89.43	10.52	56.42	28.48	6.30
1995–1996	−0.818	−50.07	0.98	66.94	34.28	51.34
1996–1997	−0.845	539.70	7.02	47.25	3673.00	629.50
1997–1998	21.500	202.30	6.36	197.70	42.90	469.80
1998–1999	−1.959	−60.13	−21.41	168.70	43.54	−429.90
1999–2000	0.072	−63944.00	−2.576	566.00	37.91	−3764.00
2000–2001	−3.247	−458.90	−9.61	843.50	43.26	417.20
2001–2002	−0.998	−1415.00	−96.14	1397.00	47.89	−64.85
2002–2003	1.950	−1088.00	−395.5	701.10	42.08	−379.1
2003–2004	0.609	−399.10	−20.41	348.30	37.19	−33.29
2004–2005	1.388	−140.60	3.81	170.50	41.90	77.19
2005–2006	−8.172	−664.80	−22.40	30.75	34.47	−353.70
2006–2007	−0.8593	−321.10	−6.66	156.00	28.75	−143.30
2007–2008	−0.529	292.10	−1.56	83.26	31.84	404.50
2008–2009	48.160	561.40	0.31	148.70	44.35	803.60
2009–2010	−10.700	−629.50	2.51	387.30	64.67	−185.90
2010–2011	2.050	−478.00	−22.22	455.30	55.05	12.240
2011–2012	−4.979	−1234.00	−37.37	934.20	51.15	−286.60
2012–2013	0.1134	253.10	0.89	47.25	52.06	352.80
2013–2014	3.147	75.37	−2.44	261.20	61.68	399.10
2014–2015	−0.044	−537.9	43.90	94.33	64.76	−374.60
2015–2016	6.196	7.82	−0.03	−31.56	57.96	110.70
2016–2017	−1.751	−354.6	12.79	65.12	56.42	−222.20
2017–2018	0.063	422.70	5.91	36.64	59.23	524.20
2018–2019	1.088	8.807	−19.92	14.60	40.02	44.62

References

Abam, F.I., Effiom, S.O., 2015. Evaluation of intensity and structural effects on energy consumption trend in Nigeria using the 3-D Decomposition Model. Int. J. Eng. Technol. Sci. 3 (6), 372–381.

Abam, F.I., Nwankwojike, B.N., Ohunakin, S.O., Ojomu, S.A., 2014a. Energy resource structure and on-going sustainable development policy in Nigeria: a review. Int. J. Energy Environ. Eng. 5, 1–16. http://dx.doi.org/10.1007/s40095-014-0102-8.

Achour, H., Belloumi, M., 2016. Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method. Transp. Policy 52, 64–71.

Andres, L., Padilla, E., 2018. Driving factors of GHG emissions in the EU transport activity. Transp. Policy 61, 60–74.

Ang, B.W., 2005. The LMDI approach to decomposition analysis: A practical guide. Energy Policy 33 (7), 867–871.

Ang, B.W., Liu, F.L., 2001. A new energy decomposition method: Perfect in decomposition and consistent in aggregation. Energy 26, 537–547.

Badmus, I., Osunleke, A.S., Fagbenle, R.O., Oyewola, M.O., 2012. Energy and exergy analyses of the Nigeria transportation sector from 1980-2010. Int. J. Energy Environ. Eng. 3, 23, 2012.

Becky, P.Y., Banister, L.D., 2016. Decoupling transport from economic growth: Extending the debate to include environmental and social externalities. J. Transp. Geogr. 57, 134–144.

Castesana, P., Puliafito, E., 2013. Bottom-up analysis of energy consumption and carbon emissions, with particular emphasis on human capital investment. Low Carbon Econ. 4 (4A2), 113.

CBN: Central Bank of Nigeria. 2007. Statistical Bulletin Volume 8. Abuja.

Chen, J., Wang, P., Cui, L., Huang, S., Song, M., 2018. Decomposition and decoupling analysis of CO_2 emissions in OECD. Appl. Energy 231, 937–950.

Dai, Y., Gao, H.O., 2016. Energy consumption in China's logistics industry: A decomposition analysis using the LMDI approach. Transp. Res. D 46, 69–80.

Dioha, M.O., Kumar, A., Daniel, R.E., Emodi, N.V., 2021. Alternative scenarios for low-carbon transport in Nigeria: A long-range energy alternative planning system model application. http://dx.doi.org/10.1016/B978-0-12-817465-4.00030-3.

Edelenbosch, O., McCollum, D., van Vuuren, D.P., Bertram, C., Carrara, S., Daly, H., Fujimori, S., Kitous, A., Ó Broin, E., Karkatsoulis, P., 2017. Decomposing passenger transport futures: Comparing results of global integrated assessment models. Transp. Res. Transp. Environ. 55, 281–293.

Effiong, M.O., Okoye, C.U., Onyekuru, N.A., 2020. Sectoral Contributions to Carbon Dioxide equivalent emissions in the Nigerian economy. Int. Energy Econ. Policy 10 (1), 456–463.

Ehrlich, P.R., Holdren, J., 1971. Impact of population growth. Science, 171(3977). Energy Build. 148, 348–354. http://dx.doi.org/10.1016/j.enbuild.2017.05.026.

Engo, J., 2018. Decomposing the decoupling of CO_2 emissions from economic growth in Cameroon. Environ. Sci. Pollution Res. Int. http://dx.doi.org/10.1007/s11356-018-3511-z.

Engo, J., 2019a. Decoupling analysis of CO2 emissions from transport sector in Cameroon. Sustain. Cities Soc. 51, 101732.

Engo, J., 2019b. Decoupling of greenhouse gas emissions from economic growth in Cameroon. Resour. Environ. Econ. 1 (1), 16–28, Available at: https://http://www.syncsci.com/journal/index.php/REE/article/view/227.

Fan, F., Lei, Y., 2016. Decomposition analysis of energy-related carbon emissions from the transportation sector in Beijing. Transp. Res. D 42, 135–145.

Gupta, M., Sing, S., 2016. Factorizing the changes in CO_2 emissions from Indian road passenger transport: A decomposition analysis, studies in Business and Economics, Lucian Blaga University of Sibiu. Fac. Econ. Sci. 11 (3), 67–83.

Hasan, M.M., Chongbo, W., 2020. Estimating energy-related CO2 emission growth in Bangladesh: The LMDI decomposition method approach. Energy Strategy Rev. 32, 100565. http://dx.doi.org/10.1016/j.esr.2020.100565.

Hossain, M.A., Songsheng, C., Khan, A.G., 2020. Decomposition study of energy-related CO2 emissions from Bangladesh's transport sector development. Environ. Sci. Pollution Res. http://dx.doi.org/10.1007/s11356-020-10846-5.

IEA, 2016. CO2 Emissions from Fuel Combustion: Highlights, two-thousand sixteenth ed. International Energy Agency, Paris, France.

IEA, 2017. CO2 emissions from fuel combustion. Available at: Oecd/Iea1-155. https://http://www.iea.org/publications/freepublications/publication/ CO2 Emissions from Fuel Combustion Highlights 2017.pdf.

INDC: Intended Nationally Determined Contribution (INDC), 2014. Federal Republic of Nigeria. http://paccpolicy.org/wp-content/uploads/2017/04/A-report-of-Nigeria-Progress-on-the-INDC.pdf.

Jian, J., 2015. A factor decomposition analysis of transportation energy consumption and related policy implications. Int. Assoc. Traffic Saf. Sci. 38, 142–148.

Jiang, X., Su, M., Li, R., 2018. Investigating the factors influencing the decoupling of transport-related carbon emissions from turnover volume in China. Sustainability 10, 3034. http://dx.doi.org/10.3390/su10093034.

Kaya, Y., 1990. Impact of Carbon Dioxide Emission on GNP Growth: Interpretation of Proposed Scenarios. Presentation to the Energy and Industry Subgroup, Response Strategies Working Group, IPCC. X'Pert Stress PW3208, Software for Residual stress analysis, PANalytical, The Netherlands, Paris, Available at: http://www.wiki.nus.edu.sg www.panalytical.com.

Kim, N., Janic, M., Van, W.B., 2009. Trade-off between carbon dioxide emissions and logistics costs based on multiobjective optimisation. Transp. Res. Rec. J. Transp. Res. Board 2139 (2139), 107–116. http://dx.doi.org/10.3141/2139-13.

Li, W., Sun, S., Li, H., 2015. Decomposing the decoupling relationship between energy related CO_2 emissions. Nat. Hazards 79 (2), 977–997.

Lopez, N.S., Chiu, A.S.F., Biona, J.B.M., 2018. Decomposition drivers of transportation energy consumption and carbon dioxide emissions for the Philippines: the case od developing countries. Front. Energy http://dx.doi.org/10.1007/s11708-081-085.

Maduekwe, Monica, Salisu Isihak, Uduak Akpan, 2020. Road transport energy consumption and vehicular emissions in lagos Nigeria: An application of the LEAP model. Transp. Res. Interdiscip. Perspect. 6, 100172.

Mousavi, B., Lopez, N.S.A., J.B.M., Biona., Chiu, A.S.F., Blesl, M., 2017. Driving forces of Iran's CO2 emissions from energy consumption: an LMDI decomposition approach. Appl. Energy 206, 804–814.

NBS: National Bureau of Statistics, 2008. Annual Abstract of Statistics. Federal Republic Nigeria, Abuja.

NBS: National Bureau of Statistics, 2020. Annual Abstract of Statistics. Federal Republic Nigeria, Abuja.

NGDPT, 2020. Nigeria's GDP from transportations sector. https://tradingeconomics.com/nigeria/gdp-from-transport. Accessed 12 20202.

NOC, 2021. Nigeria oil consumption. https://businessday.ng/energy/oil{and}gas/article/nigerians-consumed-20-8billion-litres-of-petrol-in-2019-nbs/. Accessed January 15 2021.

NPAUR, 2021. Nigeria population and urbanization rate. Accessed, January, 27 2021 at https://www.macrotrends.net/countries/NGA/nigeria/urban-population.

NPEC: Nigeria primary energy consumption accessed in https://knoema.com/atlas/Nigeria/Primary-energy-consumption. Accessed 12 August 2020.

NTP: National Transport Policy. Federal Ministry of Transport (1993). Abuja: Federal Republic of Nigeria.

Okereke, C., Diemuodeke, E.O., Acheampong, E.A., Otchwemah, H., Ahanotu, K., Olorufemi, G.A., Adegbule, W., Anieze, A.A., 2021. Policy Paper on Africa's Post COVID-19 Green Recovery: Towards a Green and Resilient Recovery in West Africa: Nigeria and Ghana. SPP publications.

Oniwon, A., 2011. Oil and Gas in Nigeria's National Development: An Assessment. A presentation at the National Defence College, Abuja.

Pan, S., Ballot, E., Fontane, F., 2013. The reduction of greenhouse gas emissions from freight transport by pooling supply chains. Int. J. ProdEconomics 143 (1), 86–94, http://www.sciencedirect.com/science/article/pii/S0925527310004160.

Robalino, L., Mena, N., Garcia, R., 2014. System dynamics modelling for green energy consumption and CO2 emissions: A case study of Ecuador. Energy Sustain. Dev. 20, 11–20.

Román-Collado, R., Morales-Carrión, A.V., 2018. Towards a sustainable growth in Latin America: A multiregional spatial decomposition analysis of the driving forces behind CO_2 emissions changes. Energy Policy 115 (January), 273–280.

Tapio, P., 2005. Towards a theory of decoupling: Degrees of decoupling in the EU andthe case of road traffic in Finland between 1970 and 2001. Transp. Policy 12 (2), 137–151, Available at: http://www.sciencedirect.com/science/article/pii/.

Tian, Xu, Geng, Yong, Zhong, Shaozhuo, Wilson, Jeffrey, Gao, C., 2018. A. bibliometric analysis on trends and characters of carbon emissions from transport sector. Transp. Res. D 59, 1–10.

Ugboaja, P.C., Ukpere, W.I., 2011. Determining economic sustainability of Nigerian national transport policy. Afr. J. Bus. Manage. 5 (8), 3139–3147, 18 April 2011 Available online at http://www.academicjournals.org/AJBM.

UNFCCC, 2015. Paris agreement. In: Conference of the Parties on Its Twenty-First Session. 21932(December), 32. Available at: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

VPN, 2020. Vehicular population in Nigeria. https://nairametrics.com/2017/12/11/vehicle-population-in-nigeria-is-11547236-nbs-data. Accessed 12 August, 2020.

Wang, S., Ge, M., 2019. Everything You Need to Know About the Fastest-Growing Source of Global Emissions: Transport. World Resources Institute, https://www.wri.org/blog/2019/10/everything-you-need-know-about-fastest-growing-source-global-emissions-transport. Accessed: 5 December 2020.

Wang, Q., LI, R., 2016. Journey to burning half of global coal: Trajectory and drivers of China's coal use. Renew. Sustain. Energy Rev. 58, 341–346.

Wang, Q., Su, M., 2020. Drivers of decoupling economic growth from carbon emission – an empirical analysis of 192 countries using decoupling model and decomposition method. Environ. Impact Assess. Rev. 81, 106356. http://dx.doi.org/10.1016/j.eiar.2019.106356.

Wang, Q., Zhang, F., 2020. Does increasing investment in research and development promote economic growth decoupling from carbon emission growth? An empirical analysis of BRICS countries. J. Clean. Prod. 252, 119853. http://dx.doi.org/10.1016/j.jclepro.2019.119853.

Wang, Q., Zhang, F., 2021. The effects of trade openness on decoupling carbon emissions from economic growth – Evidence from 182 countries. J. Clean. Prod. 279, 123838. http://dx.doi.org/10.1016/j.jclepro.2020.123838.

Wang, Q., Zhao, M., Li, R., Su, M., 2018. Decomposition and decoupling analysis of carbon emissions from economic growth: A comparative study of China and the United States. J. Clean. Prod. 197, 178–184.

Xiaoyu, H., Xu, Y., Kumar, A., Lu, X., 2018. Decoupling analysis of transportation carbon emissions and economic growth in China. Environ. Prog. Sustain. Energy Amer. Inst. Chem. Eng. http://dx.doi.org/10.1002/ep.12857.

Yang, Q., Zhu, R.H., Zhao, X.Q., 2014. Calculation decoupling analysis and scenario prediction of carbon emissions of transportation in China. Chang'an Daxue Xuebao (Ziran Kexue Ban)/J. Chang'an Univ. (Nat. Sci. Ed.) 34, 77–83.

Zhang, Z., 2000. Decoupling China's carbon emissions increase from economic growth: An economic analysis and policy implications. World Dev. 28 (4), 739–752.

Zhang, Y.J., Da, Y.-B., 2015. The decomposition of energy-related carbon emission and its decoupling with economic growth in China. Renew. Sustain. Energy Rev. 41, 1255–1266.