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Carbon Emissions Index Decomposition Analysis of the Akwa Ibom State Transportation Sector

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Abstract

This study presents the index decomposition analysis of carbon emissions in Akwa Ibom State transportation sector. The primary aim of the paper was to determine the energy consumption in the transport sector, evaluate of the economic growth of the energy consumption in the transport sector and presents the carbon emissions decoupling which results from energy consumption using Log Mean Divisia Index (LMDI) decoupling method in the transportation sector. An Index Decomposition Analysis (IDA) with Log Mean Divisia Index (LMDI) model was applied in the study. The LMDI analysis is a form of index decomposition analysis which incorporates energy changes in logarithmic mean fashion, accounting for changes regardless of emissions flow direction. The results from the emissions decoupling shows the relative contribution of the changes due to the parts of index decomposition. For the years (1990 to 2020) considered, the changes in emissions are predominantly observed in the activity effect. For the years 1993 through 2015, the activity indicator shows a large contribution to accumulation of emissions. Only the years 1991 and 1992 recorded a reduction in the overall emissions from the activity effect. In general, the trend of the emissions over the years for the transportation sector increases. On the other hand, the highest annual drop in emissions occurred in 2020, which was connected with the COVID 19 pandemic, lock down, economic crisis and recession. The study recommended that there should be improvement in energy efficiency practice and implementation of energy efficiency policies in the power sector by the Nigerian Government

1. Introduction

Decomposition analysis is one of the most effective and widely applied tools for investigating the mechanisms influencing energy consumption and its environmental side-effects. Following a few early applications in the seventies, it has known a considerable expansion during the eighties with relevant studies focusing on changes in aggregate energy consumption in the light of the preceding energy crisis. In the next decades, the interest of analysts was almost entirely shifted to the analysis

of energy-related greenhouse gas emissions because of the growing concern for climate change. In both cases, the aim was to disentangle distinct components behind historical energy and/or emissions data in order to identify the factors that may have caused the observed changes [1].
Over the past five decades, the consumption of oil products in Nigeria has maintained an upward trend, outpacing domestic production. Accordingly, this trend has created an imbalance between demand and supply in the domestic market and this can partly be attributed to limitations in the domestic refining capacity [2]. Consequently, in an attempt to address this imbalance, the Nigerian government has had to resort to importing such products. At present, more than 90% of petroleum products consumed in Nigeria are imported due to the insufficient local production [3].
Energy efficiency analysis does not just connote a reduction in utility cost but it involves increasing revenue through greater productivity. It is the indispensable component of any effort to improve productivity and of course contribute to economic wealth. Majority of the Nigerian populace are dependent on fossil fuel and fuel wood (firewood). The over dependence on fossils and fuel wood (used mainly by poor rural communities) have not yielded enough capacity to meet increasing demands. Consequently, a study of the concept of energy modelling and energy demand analysis is necessary for energy and environmental description [4].
Energy saving reflects the effects of technological progress and structural changes of an economy and indicates the total reduction of energy use if the overall economic activity remains unchanged. If the effectiveness of production technology increases, energy saving takes place while, if the share of a sector of the total production volume decreases, energy saving may also occur. Energy saving also takes into account the structural shift such as the shift towards the use of services instead of energy commodities [5].
The Logarithmic Mean Divisia Index (LMDI) method is an effective tool which takes into account the relationship between energy consumption in different sectors of economic activities and energy-related economy. It gives a differential and quantified view of the implementation of energy conservation measures. The foremost study of the application of the decomposition of energy conservation was presented in Sun [6]. However, most of the studies on energy decomposition were limited to two economic dimensions such as energy intensity and GDP. And in these trends, energy savings have been implemented in different sectors following a large collection of recent energy and gross domestic product values. Here, due to the inherent limitations of the decomposition models, the LMDI method has evolved as a strong tool for index decomposition analysis [7]; this method is to be extended to analyse the energy savings and emissions in the industrial sector of Nigeria.
Furthermore, according to Okeoma et al. [8], much of energy demand in Nigeria is from the transport sector, it is essentially important to have accurate information on utilization efficiencies and a decomposition of the emissions which comes from its usage in this sector. Such information will also guide policy makers on the extent to which prices need to be adjusted so as to control internal consumption and the potential for the market to realise the energy-efficiency objectives of government. Thus, the current study seeks to help guide policy makers and investors in making wise investment decisions in the industrial sector in the near future [9].
In recent times, concerns about carbon emissions have increased significantly, causing global warming. In order to strike a balance between energy security and the threat of climate change, it has become necessary to transform the world economy into a low-carbon economy. Accordingly, it is important to study the nexus between emissions so as to explore the impacts of the transportation structure, economic output, energy structure, energy intensity, and emission factors on the total carbon dioxide emissions. The application of energy and exergy concept in the analysis of energy studies in different sectors for a good number of countries is abundant in literature. Energy decomposition models including complete decomposition models, and recently, index decomposition analysis are used for analysing the energy savings and emissions decoupling in developing and developed economies. This brief review captures the aforementioned areas in energy analysis [9].

Utlu and Hepbasli [10] evaluated the energy and exergy utilization efficiencies in the Turkish transportation sector over the period from 2000 to 2020. A comparison of the overall energy and exergy efficiencies of the Turkish transportation sector with the other countries was also presented. Energy and exergy analyses was performed for four transport modes, namely roadway, railway, airway and seaway, while they were based on the actual data for 2000 and projected data for 2020. The results showed that roadway appears to be the most efficient mode when compared with railway, air and seaway. It is projected that about 15% of total energy resources will be used in this sector during 2020.

The energy utilization efficiencies for the Turkish transportation sector ranged from 23.71% in 2000 to 28.75% in 2020, while the exergy utilization efficiencies varied from 23.65% to 28.85% in the same years, respectively. Exergetic improvement potential for this sector was estimated to be 700 PJ in 2020, with an average increase rate of 4.5% annually between 2000 and 2020. They reported that the study will be helpful in developing highly applicable and productive planning for energy policies [11].

Volkan and Camdali [12] presented energy and exergy efficiencies in Turkish transportation sector, between 1988 and 2004. The energy efficiency was found to range from 22.16% (2002) to 22.62% (1998 and 2004) with a mean of 22.4270.14% and exergy efficiency to range from 22.39% (2002) to 22.85% (1998 and 2004) with a mean of 22.6570.15%. Overall energy and exergy efficiencies of the transport sector consist mostly of energy and exergy efficiencies of the highways subsector in percentages varying from 81.5% in 2004 to 91.7% in 2002.

The rest of them are consisted of other subsectors such as railways, seaways, and airways. The overall efficiency patterns are basically controlled by the fuel consumption in airways in spite of this subsector's consisting only a small fraction of total. The major reasons for this are that airways efficiencies and the rate of change in fuel consumption in airways are greater than those of the others. Furthermore, the study results showed that airway transportation should be increased to improve the energy and exergy efficiencies of the Turkish transport sectors. However, it should also be noted that no innovations and other advances in transport technologies are included in the calculations [13].

Suleiman and Salamatu [3] analysed the demand for petroleum products in Nigeria using time series data (1980-2013). The estimated elasticities were compared with those of similar studies in developing countries. The outcome shows that there is no significant difference between the findings of this study and previous studies in similar contexts. The results suggest that consumption of individual products is more elastic to changes in income than real prices. The income elasticities of demand were 0.6513 for the aggregate, 0.5886 for gasoline and 1.3456 for diesel.

Zarifi et al. [14] analysed and investigated the energy and exergy utilization of the transportation sector in Iran for the period of 1998–2009. The total energy consumption in each subsector and the overall energy and exergy efficiencies were predicted via scenario approach. A comparison of the overall energy and exergy efficiencies of Iran with six other countries was also presented. The results showed that the overall energy and exergy efficiencies of transportation sector in Iran is higher than China and Norway, while it is lower than Saudi Arabia, Jordan, Turkey, and Malaysia for the year 2000. Road appears to be the most efficient subsector. The overall energy efficiency was determined to be in the range of 22.02% in 1998, to 21.49% in 2009, while the overall exergy efficiency is determined to be in the range of 21.47% in 1998, to 21.19% in 2009. The energy consumption in each subsector was predicted from 2010 to 2035. It was discovered that the overall energy and exergy efficiencies possesses an upward trend during this time period.

Until now, a study on the current and future energy and exergy efficiencies in the Nigerian transportation sector using econometric approaches with predicted forecast has not been done. Accordingly, this research work intends to fill this void by considering thermodynamic and econometric analysis of energy efficiencies in the transportation sector. Such information will guide policy makers on the extent to which prices need to be adjusted so as to control internal consumption and the potential for the market to realise the energy-efficiency objectives of government. Thus, the

current study seeks to help guide policy makers and investors in making wise investment decisions in the transport sector in the near future [15].
The general objective is the index decomposition analysis of carbon emissions in the transportation sector based on application of the Logarithmic Mean Divisia Index Method.
The specific objectives were to: determine of energy consumption in the transport sector, evaluate of the economic growth of the of energy consumption in the transport sector and present the carbon emissions decoupling which results from energy consumption using LMDI decoupling method in the transportation sector.
Akwa Ibom State is one of the 36 states in the Nigerian Federation. It has an estimated current population of 3.92 million (NPC,2006). Created on 23rd September, 1987, it is the tenth largest state in the country with 31 Local Government Areas. The state covers a total area of 7,246.499square kilometers. It is located in the coastal South-south part of Nigeria and lies approximately between latitudes 432' N and 533'N and longitudes 725' E and 825' E. The state is bounded on the East by Cross Rivers State, on the West by Rivers State and Abia State and on the South by Atlantic Ocean. Akwa Ibom State Transport Company (AKTC) was established in 1988 after the creation of Akwa Ibom state in (1987), for the purpose of bringing speedy economic activities to the state. Hence, the establishment of AKTC an off shoot of Federal Urban Mass Transport Programme (FUMTP) came into being precisely in February, 1988 vested with responsibility of conveying goods and services to the masses. AKTC has been continually replenished and reinvigorated by the government until late 90's when the co-operation metamorphosed into a limited liability company.

2. Methodology

2.1 The Index Decomposition Analysis (IDA) approach

The conventional IDA approach for the decomposition of aggregate energy consumption change into the activity, structure and intensity effects is applied to specific transportation subsectors and similar arrangements where physical production data is available and the products are similar. Samples of such studies are obtained in [16] and [17] for iron and steel [18], for pulp and paper, and [19] for several subsectors which includes aluminum and cement. Here, it is applied to the transportation sector. In these studies, the overall activity level has been estimated by summing the physical production of the considered products. Since this is reasonable only if the products are homogenous, these studies are generally subsector-specific. When IDA is applied to the entire industry sector, such as in [20] and [21], aggregate energy consumption change is decomposed to give only two effects, i.e., production effect and physical intensity effect.
The production effect gives the contribution of the weighted sum of the changes in the physical production of individual products, while the physical intensity effect quantifies the overall contribution of changes in energy requirements to produce each unit of product. The activity effect and structure effect, which cannot be separately quantified, are embedded in the production effect. To overcome this drawback, two solutions have been proposed. Farla and Blok [22] derived the activity and structure effects using monetary activity data as is the case in the conventional IDA, and refactorized the monetary intensity effect into the physical intensity effect and a new term called the dematerialization effect. This leads to a four-factor IDA identity. The second solution, as used in OEE [23] is to retain the conventional three-factor IDA identity but adjust the activity and structure effects using the additional information provided by subsector physical activity data. The activity value of each product is revaluated to reflect changes in physical production level, which leads to a new way of defining and interpreting the three effects. These methods have been applied here for the transportation sector where a knowledge of the contribution of changes in energy decoupling is required using the logarithmic mean divisia index.

2.2 Sources of data

Structured data from the archives of the nation's economic growth and accompanying carbon dioxide emissions was extracted from Nigeria Bureau of Statistics Bulletin (for Akwa Ibom State). Gross Domestic Product (GDP), the energy consumption, as well as the energy intensity in appropriate units was extracted from Central Bank of Nigeria Statistical Bulletin. The methods for the analysis include the estimation of energy changes for the years with regards to a 31 year preceding data and the emissions which is decoupled in terms of the activity, intensity, structural change, energy, and emissions matrix effect [24]. The data for the analysis of the sector is presented below:

Table 1 Annual energy consumption, GDP, and structure for road transportation sector

YEAR	Land		
	Energy (PJ)		GDP (N'million)
	PMS	AGO	
1990	121.7725	33.43869	N/A
1991	152.9379	39.31714	2326.70
1992	171.9794	41.96783	1905.10
1993	177.8283	43.31493	1860.90
1994	169.3456	40.37992	2089.80
1995	169.1236	37.06686	3030.50
1996	154.016	31.8384	3171.10
1997	155.5185	29.60361	3430.02
1998	165.428	32.69032	3709.98
1999	187.5791	34.40722	4019.58
2000	185.69	40.98399	4665.62
2001	185.7925	41.00136	5293.84
2002	187.1253	32.13304	8050.81
2003	226.9443	57.92496	13548.18
2004	239.8583	39.73802	29826.64
2005	175.6138	38.98208	46687.45
2006	169.48	38.95989	60621.68
2007	168.4867	45.59488	69676.07
2008	150.1318	31.13056	90067.63
2009	134.116	27.371	106212.07
2010	190.2686	38.30822	116337.70
2011	250.76	46.13529	129967.75
2012	275.4001	41.35251	160679.90
2013	271.5041	39.35402	205936.69
2014	258.2866	24.72426	344913.02
2015	307.2292	34.92473	362605.26
2016	376.2422	23.36103	416240.26
2017	328.5612	10.77207	444989.96
2018	306.4878	21.89909	450329.84
2019	292.4471	11.15277	475907.25
2020	386.5995	22.98541	495756.16

Source: NBS and CBN statistical bulletin 2022

2.3. 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^Ti.e. $V = \sum_i V_i$ and $V_i = x_{1,i}, x_{2,i}, \ldots x_{n,i}$, then the contributions of the n factors to the change in the aggregate can be expressed as Ang and Liu [25]:

$$\Delta V_{TOT} = V^T - V^0 = \Delta V_{x1} + \Delta V_{x2} + \cdots + \Delta V_{xn} \qquad 1$$

2.4 Logarithmic Mean Divisia Index Method

The general expression for the logarithmic mean divisia index method is expressed as (Ang and Liu [25]:

$$\Delta V_{xk} = \sum_i L\left(V_{i,}{}^T V_i{}^0\right) ln\left(\frac{x_{k,i}{}^T}{x_{k,i}{}^0}\right) \qquad 2$$

The logarithmic mean of the aggregate $\boldsymbol{V}$ is expressed with the relationship:

$$L\left(V_{i,}{}^T V_i{}^0\right) = \frac{V_{i,}{}^T - V_{i,}{}^0}{\ln\left(V_{i,}{}^T\right) - \ln\left(V_{i,}{}^0\right)} \qquad 3$$

The relative contribution of the terms which constitutes the effects of energy decomposition are expressed with the LMDI method with the relationships expressed below:

$$\Delta E_{activity} = \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{Q^T}{Q^0}\right] \qquad 4$$

$$\Delta E_{intensity} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{I_i{}^T}{I_i{}^0}\right] \qquad 5$$

$$\Delta E_{structure} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{S^T}{S^0}\right] \qquad 6$$

The development of the LMDI method is based on equation 1 which is expressed in terms of the energy consumption as:

$$\Delta E_{TOT} = E^T - E^0 = \Delta E_{x1} + \Delta E_{x2} + \cdots + \Delta E_{xn} \qquad 7$$

The expression in equation 3.7 can be altered to the form:

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

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

$$\Delta E_{TOT} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{Q^T S_i{}^T I_i{}^T}{Q^0 S_i{}^0 I_i{}^0}\right] \qquad 9$$

Expanding the natural logarithm term in equation 9, the following expression is obtained:

$$\Delta E_{TOT} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) \left(ln\left[\frac{Q_i{}^T}{Q_i{}^0}\right] + ln\left[\frac{S_i{}^T}{S_i{}^0}\right] + ln\left[\frac{I_i{}^T}{I_i{}^0}\right]\right) \qquad 10$$

By expanding equation 10, the following form of the expression is obtained:

$$\Delta E_{TOT} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{Q_i{}^T}{Q_i{}^0}\right] + \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{S_i{}^T}{S_i{}^0}\right] + \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{I_i{}^T}{I_i{}^0}\right] \qquad 11$$

2.5 Carbon dioxide emissions decoupling

The empirical model required to calculate the quantity of carbon dioxide emissions from fossil energy is presented by quantifying the contributions of five different factors: scale of the economy, industrial activity mix, sectoral energy intensity, sectoral energy mix, and the values of emission factors. Additionally, different sub-categories are considered, concerning industrial sectors and fuel type. The carbon dioxide emissions can be written as (Robalino [27, 28]:

$$C = \sum_{ij} C_{ij} = Q \sum_{ij} \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = Q \sum_{ij} S_i * I_i * M_{ij} * U_{ij} \quad 12$$

The terms of equation 12 are labelled as follows:
$\boldsymbol{C}$ is the total carbon dioxide emissions for the whole sectors in a given year;
$\boldsymbol{C_{ij}}$ is the total carbon dioxide emissions arising from fuel type ***j*** in the ***i^th^*** sector;
$\boldsymbol{Q}$ is the total GDP of the country;
$\boldsymbol{Q_i}$ is the GDP generated by the $\boldsymbol{i^{th}}$ sector;
$\boldsymbol{E_i}$ is the energy consumption in the $\boldsymbol{i^{th}}$ sector;
$\boldsymbol{E_{ij}}$ is the energy due to consumption of fuel ***j*** in the $\boldsymbol{i^{th}}$ sector;
$\boldsymbol{S_i}$ is the share of the GDP of the $\boldsymbol{i^{th}}$ sector to the total GDP of the considered sectors;
$\boldsymbol{I_i}$ is the energy intensity in the $\boldsymbol{i^{th}}$ sector;
$\boldsymbol{M_{ij}}$ is the energy matrix expressed for the $\boldsymbol{i^{th}}$ sector as the energy from fuel type ***j*** to the total energy in the sector;
$\boldsymbol{U_{ij}}$is the carbon dioxide emission factor for the $\boldsymbol{i^{th}}$ sector.
Although very detailed data as outlined in the expressions above for particular sectors and the fuel types are not readily available for Nigeria, however, a sum of the nation's economic growth and accompanying carbon dioxide emissions can be found in the Nigeria Bureau of Statistics Bulletin as well as the Central Bank of Nigeria Statistical Bulletin annually. Following the methods for the LMDI analysis, equation 12 can be written as follows according to Ang et al [29]:

$$\Delta C_{TOT} = {C_i}^T - {C_i}^0 = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} + \Delta V_{emf} \quad 13$$

The expression in equation 3.13 can be altered to the form:

$$\Delta C_{TOT} = \sum_i \left(\frac{{C_i}^T - {C_i}^T}{ln[{C_i}^T] - ln[{C_i}^0]} \right) ln \left[\frac{{C_i}^T}{{C_i}^0} \right] \quad 14$$

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

$$\Delta C_{TOT} = \sum_i \left(\frac{{C_i}^T - {C_i}^0}{ln[{C_i}^T] - ln[{C_i}^0]} \right) ln \left[\frac{Q^T {S_i}^T {I_i}^T {M_{ij}}^T {U_{ij}}^T}{Q^0 {S_i}^0 {I_i}^0 {M_{ij}}^0 {U_{ij}}^0} \right] \quad 15$$

Expanding the natural logarithm term in equation 3.15, the following expression is obtained:

$$\Delta C_{TOT} = \sum_i \left(\frac{{C_i}^T - {C_i}^0}{ln[{C_i}^T] - ln[{C_i}^0]} \right) \left(ln \left[\frac{{Q_i}^T}{{Q_i}^0} \right] + ln \left[\frac{{S_i}^T}{{S_i}^0} \right] + ln \left[\frac{{I_i}^T}{{I_i}^0} \right] + ln \left[\frac{{M_{ij}}^T}{{M_{ij}}^0} \right] + ln \left[\frac{{U_{ij}}^T}{{U_{ij}}^0} \right] \right) \quad 16$$

By expanding equation 3.16, the following form of the expression is obtained:

$$\Delta E_{TOT} = \sum_i \left(\frac{{C_i}^T - {C_i}^0}{ln[{C_i}^T] - ln[{C_i}^0]} \right) ln \left[\frac{Q^T}{Q^0} \right] + \sum_i \left(\frac{{C_i}^T - {C_i}^T}{ln[{C_i}^T] - ln[{C_i}^0]} \right) ln \left[\frac{{S_i}^T}{{S_i}^0} \right] + \sum_i \left(\frac{{C_i}^T - {C_i}^T}{ln[{C_i}^T] - ln[{C_i}^0]} \right) ln \left[\frac{{I_i}^T}{{I_i}^0} \right] + \sum_i \left(\frac{{C_i}^T - {C_i}^T}{ln[{C_i}^T] - ln[{C_i}^0]} \right) ln \left[\frac{{M_{ij}}^T}{{M_{ij}}^0} \right] + \sum_i \left(\frac{{C_i}^T - {C_i}^T}{ln[{C_i}^T] - ln[{C_i}^0]} \right) ln \left[\frac{{U_{ij}}^T}{{U_{ij}}^0} \right] \quad 17$$

Each of the terms in equation 17 is expressed as:

$$\Delta C_{act} = \sum_i \left(\frac{{C_{ij}}^T - {C_{ij}}^0}{ln[{C_{ij}}^T] - ln[{C_{ij}}^0]} \right) ln \left[\frac{Q^T}{Q^0} \right] \quad 18$$

$$\Delta C_{str} = \sum_i \left(\frac{{C_{ij}}^T - {C_{ij}}^0}{ln[{C_{ij}}^T] - ln[{C_{ij}}^0]} \right) ln \left[\frac{{S_i}^T}{{S_i}^0} \right] \quad 19$$

$$\Delta C_{int} = \sum_i \left(\frac{{C_{ij}}^T - {C_{ij}}^0}{ln[{C_{ij}}^T] - ln[{C_{ij}}^0]} \right) ln \left[\frac{{I_i}^T}{{I_i}^0} \right] \quad 20$$

$$\Delta C_{mix} = \sum_i \left(\frac{{C_{ij}}^T - {C_{ij}}^0}{ln[{C_{ij}}^T] - ln[{C_{ij}}^0]} \right) ln \left[\frac{{M_{ij}}^T}{{M_{ij}}^0} \right] \quad 21$$

$$\Delta C_{emf} = \sum_i \left(\frac{{C_{ij}}^T - {C_{ij}}^0}{ln[{C_{ij}}^T] - ln[{C_{ij}}^0]} \right) ln \left[\frac{{U_{ij}}^T}{{U_{ij}}^0} \right] \quad 22$$

The expressions obtained in equations 18 through 22 contain the emissions decoupling which results due to the burning of fossil fuel in the industrial sector. The computation above adopted the LMDI decomposition analysis developed by Ang and Liu [25] who provided a practical guide that included the general formulation process and summary tables for easy reference.

3. Results

3.1 Emissions decomposition

The carbon dioxide emissions and corresponding energy output which is reflected in the GDP have been presented in Tables 1 and 2 for the Akwa Ibom State transport sector for the years 1990 to 2020. The considered transportation subsectors is land modes of transportation. Following the methods for the analysis of emissions decomposition into effects, results are presented accordingly. Sample calculation for the year 2014 is made in the light of the LMDI model.
The LMDI analysis is a special form of index decomposition analysis which incorporates energy changes in logarithmic mean fashion, accounting for changes regardless of emissions flow direction. A structured data which caters for the intensity of energy consumption is presented. The emission factors for the fuels are enlisted below:

Table 2 Fuel related emissions factors

Fuel	PMS
Emissions tCO2/GJ	67.4
Emissions tCO2/PJ	67400000

Source: Ang et al [29].

Using the emission factors tabulated above, with reference to Equ. 12, Tables 2 and 3 are computed for the various fuels.

Table 3 Carbon dioxide emissions for land modes

Year	Land			
	PMS (PJ)	Emissions tCO_2/PJ	AGO (PJ)	Emissions tCO_2/PJ
1990	121.7725	8207466.5	33.43869	233736.4431
1991	152.9379	10308014.46	39.31714	274826.8086
1992	171.9794	11591411.56	41.96783	293355.1317
1993	177.8283	11985627.42	43.31493	302771.3607
1994	169.3456	11413893.44	40.37992	282255.6408
1995	169.1236	11398930.64	37.06686	259097.3514
1996	154.016	10380678.4	31.8384	222550.416
1997	155.5185	10481946.9	29.60361	206929.2339
1998	165.428	11149847.2	32.69032	228505.3368
1999	187.5791	12642831.34	34.40722	240506.4678
2000	185.69	12515506	40.98399	286478.0901
2001	185.7925	12522414.5	41.00136	286599.5064
2002	187.1253	12612245.22	32.13304	224609.9496
2003	226.9443	15296045.82	57.92496	404895.4704
2004	239.8583	16166449.42	39.73802	277768.7598
2005	175.6138	11836370.12	38.98208	272484.7392
2006	169.48	11422952	38.95989	272329.6311

2007	168.4867	11356003.58	45.59488	318708.2112
2008	150.1318	10118883.32	31.13056	217602.6144
2009	134.116	9039418.4	27.371	191323.29
2010	190.2686	12824103.64	38.30822	267774.4578
2011	250.76	16901224	46.13529	322485.6771
2012	275.4001	18561966.74	41.35251	289054.0449
2013	271.5041	18299376.34	39.35402	275084.5998
2014	258.2866	17408516.84	24.72426	172822.5774
2015	307.2292	20707248.08	34.92473	244123.8627
2016	376.2422	25358724.28	23.36103	163293.5997
2017	328.5612	22145024.88	10.77207	75296.7693
2018	306.4878	20657277.72	21.89909	153074.6391
2019	292.4471	19710934.54	11.15277	77957.8623
2020	386.5995	26056806.3	22.98541	160668.0159

Source: NBS and CBN statistical bulletin 2022

The emissions which results from the consumption of energy in the various subsectors are shown in Tables 2 and 3. The emissions trend varies linearly with the quantity of annual yearly consumption and the type of fuel usage. A decomposition of the emissions trend based on the LMDI method is presented for each of the effective parametric variation for the year 2004. Sub sectoral energy intensity, structure and GDP values are needed for a detailed computation. The values presented in Table 4.

Table 4 Sub sectoral GDP structure and energy intensity

Year	Land	
	S	**I**
1990	N/A	N/A
1991	0.8326	0.08263
1992	0.765685	0.112302
1993	0.755634	0.118837
1994	0.791681	0.100357
1995	0.838753	0.068038
1996	0.843752	0.058609
1997	0.856561	0.053971
1998	0.860345	0.053401
1999	0.880153	0.055226
2000	0.887868	0.048584
2001	0.891351	0.042841
2002	0.919854	0.027234

2003	0.929621	0.021026
2004	0.963751	0.009374
2005	0.97214	0.004596
2006	0.9756	0.003438
2007	0.974959	0.003073
2008	0.979338	0.002013
2009	0.980715	0.00152
2010	0.979631	0.001965
2011	0.979426	0.002284
2012	0.979553	0.001971
2013	0.982784	0.001509
2014	0.988746	0.000821
2015	0.988354	0.000944
2016	0.987913	0.00096
2017	0.987247	0.000763
2018	0.987248	0.000729
2019	0.986522	0.000638
2020	0.985625	0.000826

Source: NBS and CBN statistical bulletin 2022

3.2 Emissions based on activity:

Referring equation 3.18 and the Tables 1, 2, 3 and 4, the activity based emissions are calculated as:

$$\Delta C_{activity} = \frac{[17408516.84 - 18299376.34]}{\ln(17408516.84) - \ln\,(18299376.34)} * ln\left(\frac{344913.02}{205936.69}\right) + \frac{(172822.5774 - 275084.5998)}{ln(172822.5774) - \ln(275084.5998)} * ln\left(\frac{344913.02}{205936.69}\right) + \frac{(221300.856 - 996590.568)}{ln(221300.856) - \ln(996590.568)} * ln\left(\frac{3009.64}{2759.18}\right) + \frac{(165803.7 - 494801.9)}{ln(165803.7) - \ln(494801.9)} * ln\left(\frac{909.92}{842.40}\right) + \frac{(25923.39 - 41262.69)}{ln(25923.39) - \ln(41262.69)} * ln\left(\frac{909.92}{842.40}\right) + \frac{(8415.96 - 10519.95)}{ln(8415.96) - \ln(10519.95)} * ln\left(\frac{6.41}{5.92}\right)$$

$$\Delta C_{activity} = 9390510.713\ \mathrm{t}CO_2$$

Following similar computations for the activity effect, economic structure, intensity, energy matrix and the emissions effects tabulations are made and presented as follows:

Table 5 Summary of carbon dioxide emissions decoupling

Year	$\Delta C_{activity}$ tCO_2	ΔC_{str} tCO_2	ΔC_{int} tCO_2	ΔC_{mix} tCO_2	ΔC_{emf} tCO_2
1992	-1425239.943	236015.2307	2964418.959	7.293471035	-0.023129335
1993	-263839.4078	-105825.5919	780137.8695	0.262925875	0.015109887
1994	1458941.403	401625.4338	-2304001.295	-96.66863285	0.00994906
1995	4762011.292	122602.3904	-4989402.716	-0.513973806	0.000456137
1996	373632.7452	-153038.1248	-3078956.722	204.0214531	-0.001180779
1997	963782.027	181659.0783	-885714.1104	7.773063018	-0.058959339
1998	975360.9517	41365.10802	-557505.1726	1.899674841	0.024474411
1999	932107.215	156519.3437	452358.2536	-37.00622848	0.008101499
2000	2355322.482	115913.6621	2760469.593	-19.25229413	-0.009679931
2001	-	-	-	-	-
2002	5744960.935	180715.6056	-6005027.774	-1.229430544	0.045869085
2003	8001989.593	-51972.11545	-4290550.838	898.8639873	-0.045984053
2004	13005201.98	-179799.2173	-13534561.36	200.1000672	-0.01689289
2005	6616806.813	-252518.6799	-10224844.96	-30.40368519	0.041909866
2006	3311384.14	-173581.8462	-3649885.92	44.45213261	0.00382981
2007	1934319.609	40251.49111	-1237800.448	15.3993118	0.028657987
2008	2879310.075	-162268.9426	-6182124.099	-191.6481335	-0.040910969
2009	1639454.201	-33872.0513	-2905260	-428.6333289	-0.055228821
2010	1030567.225	-9073.119136	2726907.017	-5063.618396	0.025845275
2011	1792285.835	14329.40008	6300857.67	59.2867501	-0.004292706
2012	4420416.601	133213.2877	-6590875.421	98.02074967	-0.002490093
2013	4731172.331	-140919.9836	-4782365.721	16655.30271	0.004525567
2014	9390510.713	-253007.6931	-12095622.98	-1189.36366	-0.036337953
2015	984082.1592	873.2764899	2506500.834	100.167895	0.050344589
2016	3248108.43	-5547.557793	985714.7791	1016.176306	-0.00836994
2017	1699793.792	33410.96737	-5537990.941	-580.9843125	-0.011206826
2018	276305.9834	21.77990336	830713.7889	-47.94674592	0.012375668
2019	1412909.302	142326.3418	-3697377.797	-244.1324782	-0.053317438
2020	1062971.316	58987.77735	4352349.16	-86.664152	0.025252191

The results from emissions decoupling shows the relative contribution of the changes due to the parts of index decomposition. For the years considered, the changes in emissions are predominantly observed in the activity effect. For the years 1993 through 2015, the activity indicator shows a large contribution to accumulation of emissions. Only the years 1991 and 1992 recorded a reduction in the overall emissions from the activity effect. In general, the trend of the emissions over the years for the transportation sector increases as shown in Fig. 1.

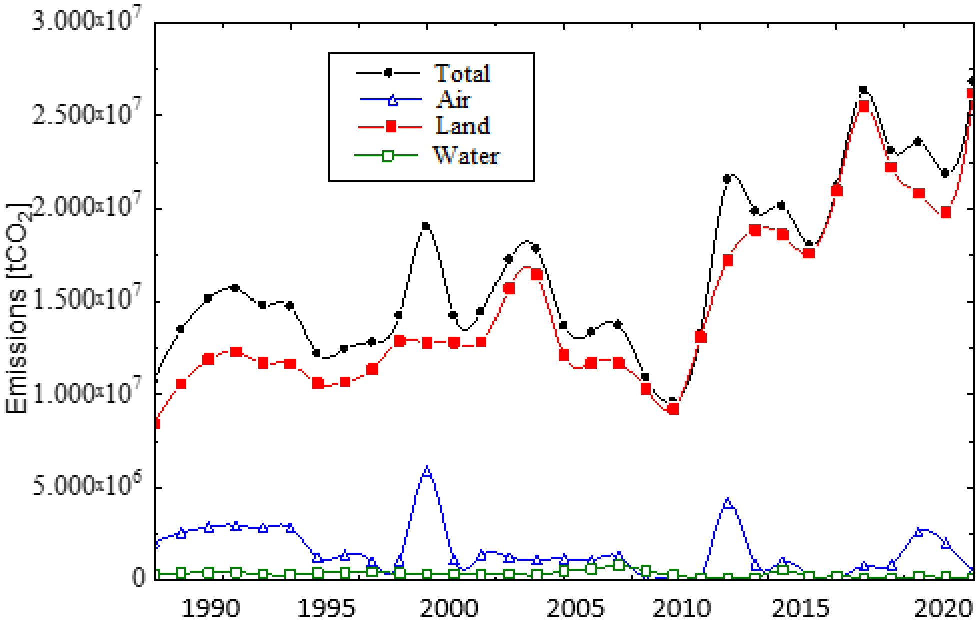

Fig. 1 Carbon dioxide emissions from the transportation sector

In summary, as reflected on the results shown in Fig. 1, land mode of transportation accounts for a high part of emissions.

4. Conclusion

This project investigated the factors influencing the increase in carbon dioxide emissions in Nigeria. The LMDI method of decomposition was employed and the main results showed that those economic activities contributed the most to the increase in carbon dioxide emissions. The key findings of the study include:

i. The results from emissions decoupling shows the relative contribution of the changes due to the parts of index decomposition.
ii. For the years considered, the changes in emissions are predominantly observed in the activity effect. For the years 1993 through 2015, the activity indicator shows a large contribution to accumulation of emissions.
iii. Only the years 1991 and 1992 recorded a reduction in the overall emissions from the activity effect. In general, the trend of the emissions over the years for the transportation sector increases
iv. Finally, land mode of transportation accounts for the high part of emissions

From these results, the study recommended that there should be improvement in energy efficiency practice and implementation of energy efficiency policies in the power sector by the Nigerian Government.

References

[1] Abam FI, Nwankwojike BN, Ohunakin OS, Ojomu SA (2014). Energy resource structure and on-going sustainable development policy in Nigeria: a review. *International Journal of Energy and Environmental Engineering*. 5:102.
[2] Ang B.W., Liu F. L., Chew E. (2003). Perfect decomposition techniques in energy and environmental analysis. *Energy Policy* 31, 1561–1566.

[3] Suleiman S. and Salamatu I (2016). Empirical analysis of transportation demand for oil products in Nigeria: Using error correction approach. *Energy Strategy Reviews* 10. 53-61.
[4] Ang BW, Choi KH. (1997). Decomposition of aggregate energy and gas emission intensities for industry: a refined Divisia index method. *The Energy Journal*. 18:59-73.
[5] Diakoulaki, D.,Mavrotas, G.,Orkopoulos, D., Papayannakis, L., (2006). A bottom-up decomposition analysis of energy related CO2 emission in Greece. Energy 31, 2638–2651.
[6] Sun J W (2003). Dematerialization in Finnish energy use, 1972-1996, *Energy Economics,* 25: 23-32.
[7] Ang, B.W., Liu, F.L., (2001). A new energy decomposition method: perfect in decomposition and consistent in aggregation. *Energy Policy* 26, 537–548.
[8] Okeoma, T.F, Nwachukwu E. I., Ezeonye, C.S, and Osatemple M (2023) A Study on the Impact of Energy Consumption on the Nigerian Economy. Journal of Energy Technology and Environment Vol. 5(1) 2023 pp. 40 - 52 ISSN-2682-583. https://doi.org / 10.5281/zenodo.7741150
[9] Ang BW, Zhang FQ, Choi KH (1998). Forecasting changes in energy and environmental indicators through decomposition analysis. *Energy.* 23(6):489-495.
[10] Okeoma T. F, Amaechi, U. G and Nwachukwu E. I (2023). Impact of Power Generating Capacity on the Nigerian Economy. Journal of Energy Technology and Environment Vol. 5(1) 2023 pp. 1 - 12 ISSN-2682-583x1. https://doi.org/10.5281/zenodo.7740890
[11] Zarifi F., Mahlia T.M.I., Motasemi F., Shekarchian M., Moghavvemi M (2013). Current and future energy and exergy efficiencies in the Iran's transportation sector. *Energy Conversion and Management* 74. 24–34.
[12] Volkan S E and Camdali U (2007). Energy and exergy efficiencies in Turkish transportation sector, 1988–2004. *Energy Policy* 35. 1238–1244.
[13] Volkan S E and Camdali U (2007). Energy and exergy efficiencies in Turkish transportation sector, 1988–2004. *Energy Policy* 35. 1238–1244.
[14] Zarifi F., Mahlia T.M.I., Motasemi F., Shekarchian M.,Moghavvemi M. Current and future energy and exergy efficiencies in the Iran's transportation sector. Energy Conversion and Management 74 (2013) 24–34.
[15] Ang BW (1995). Multilevel decomposition of industrial energy consumption. *Energy Economics*; 17(1):39–51.
[16] Worrell, E., Price, L., Martin, N., Farla, J., Schaeffer, R., (1997). Energy intensity in the iron and steel industry: a comparison of physical and economic indicators. *Energy Policy* 25, 727–744.
[17] Ozawa, L., Sheinbaum, C., Martin, N., Worrell, E., Price, L., (2002). Energy use and CO2 emissions in Mexico's iron and steel industry. *Energy journal* 27, 225–239.
[18] Farla, J.C.M., Blok, K., (2000). Energy efficiency and structural change in the Netherlands, 1980–1995. *J. Ind. Ecol.* 4, 93–117.
[19] Reddy, B.S., Ray, B.K., 2011. Understanding industrial energy use: physical energy intensity changes in Indian manufacturing sector. *Energy Policy* 39, 7234–7243.
[20] Diakoulaki, D.,Mavrotas, G.,Orkopoulos, D., Papayannakis, L.,2006. A bottom-up decomposition analysis of energy related CO2 emission in Greece. Energy 31, 2638–2651.
[21] Salta M, Polatidis H, Haralambopoulos D. (2009). Energy use in the Greek manufacturing sector: A methodological framework based on physical indicators with aggregation and decomposition analysis, *Energy* 34. 90–111.
[22] Farla, J., Blok, K., Schipper, L., 1997. Energy efficiency developments in the pulp and paper industry: a cross-country comparison using physical production data. Energy Policy 25, 745–758.
[23] OEE, (2003). Methodology for Analysing the Factorization of Energy Consumption. *Natural Resources Canada, Ottawa.*
[24] Lan-Cui Liua, Ying Fan, Gang Wu, Yi-Ming Wei. Using LMDI method to analyse the change of China's industrial CO2 emissions from final fuel use: An empirical analysis, Energy Policy 35 (2007) 5892–5900.
[25] Ang, B.W., (2004). Decomposition Analysis for Policy Making in Energy: which is the Preferred Method? Energy Policy 32, 1131–1139.
[26] Ang, B.W., (2005). The LMDI Approach to Decomposition Analysis: a Practical Guide. *Energy Policy* 33, 867–871.
[27] Robalino L., Garcia R., Golpe A., and Mena N. (2013). "System dynamics modelling and the Environmental Kuznets Curve in Ecuador (1980-2025)". *Energy Policy* 67, 923-931.
[28] Robalino L., Mena N., and Garcia R. (2014). "System dynamics modelling for green energy consumption and CO2 emissions: A case study of Ecuador". *Energy for Sustainable Development* 20, 11-20.
[29] Ang, B.W., Liu, F. L., Chung, H. S., (2002). Index numbers and the Fisher ideal index approach in energy decomposition analysis. Research Report 38/2002, Department of Industrial and Systems Engineering, National University of Singapore.