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3D Log-Mean Divisia Index Approach to the Prediction Modelling of Sectoral Energy Savings and Consumption Trends in Nigeria

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Abstract
Sufficient modelling and prediction of energy consumption constitute vital roles in developed and developing countries for policy makers and related organizations. Underestimating energy consumption patterns can lead to severe outages, while overestimating it can result in unnecessary idle capacity and wasted financial resources. This research presents a forecast on sectoral energy savings and consumption in Nigeria using a novel combination of the 3-D decomposition and logarithmic mean divisia index methods (LMDI). Energy savings and projections were made using the 3-D decomposition method while energy efficiency evaluations were presented using the LMDI method. With energy consumption, gross domestic product, and energy intensity data, energy consumption and GDP were projected up to 2050 in the industrial, transportation and agricultural sectors. Corresponding energy efficiency trend and rebound effects were considered using the LMDI approach. Energy forecast results show that the aggregate energy demand in Nigeria by the end of 2050 will increase from 75323176 to 99974700 toe compared to the 2015 level. Consequently, energy materialisation is expected to increase from 47281.15 to 658772.33 toe between 2025 and 2050. Sectoral energy savings present the country as having an energy over-consumption of 129821445.35, 16285998.43, and 6342692.71 toe for the industrial, transport and agricultural sectors, respectively, during 1990 to 2011. The industrial sector is the major driver in the country requiring emphasis in the energy conservation plan. Furthermore, for proper policy recommendation and implementation, it is strongly suggested that a detailed study of the sub-sectors be considered using any appropriate index decomposition analysis method.

Keywords: *Sectoral, Energy, Prediction, Efficiency, Rebound effects*

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1. Introduction

Nigeria and the economies of the world rely heavily on energy as a driver of all economic activities (Rahman and Alam, 2021). Higher energy consumption leads to more economic activity in the country, leading to a larger economy. Nigeria has a high level of natural resources, including potential energy resources, as one of Africa's largest developing nations. Rising Nigerian access to energy has nevertheless been an ongoing and urgent challenge to the international community. Economic growth, which is necessary to the nation to improve its developmental path, will facilitate a highly improved level of economic growth by using its energy potential to respond to demand.

Adequate energy usage can be estimated using a number of econometric methods with corresponding economic growth. The decomposition method is an effective tool that recognizes the relationship between energy consumption in various economic and energy sectors. It gives the implementation of energy conservation measures a differential and quantified view. The foremost study of the application of the decomposition of energy conservation was presented in Sun (2003). Many energy decomposition studies however were limited to two economic dimensions, such as energy intensity and GDP. And, following a large collection of recent energy sources and gross domestic product values, energy savings have been implemented in different sectors.

The conventional IDA approach for the decomposition of aggregate energy consumption change into the activity, structure and intensity effects is applied to specific industrial subsector where physical production data are available and the products are similar. Samples of such studies are obtained in Worrell et al. (1997) and Ozawa et al. (2002) for iron and steel, Farla et al. (1997) for pulp and paper, and Reddy and Ray, (2011) for several subsectors which include aluminium and cement. In these studies, the overall activity level was estimated by summing the physical production of the considered products. Since this is reasonable only if the products are homogenous, these studies were generally subsector specific. When IDA is applied to the entire industry sector, such as in Diakoulaki et al. (2006) and Salta et al. (2009), aggregate energy consumption change was 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 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 (2000a) 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 led to a four-factor IDA identity. The second solution, as used in OEE (2003) 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 re-evaluated to reflect changes in physical production level, which leads to a new way of defining and interpreting the three effects.

The application of the decomposition techniques as an analytical economic tool for energy savings has attracted wider interest and application in recent times. Its use has extended to industrial energy demand estimation, energy modelling and energy environmental description (Ang et al., 1998; Ediger and Huvaz, 2006). In these techniques, changes in energy consumption are decomposed into production, efficiency and structural effects, by taking into accounts the correlation between energy use and energy associated economy. Many scholars have applied this technique across different economic sectors globally. Some have used this technique with emphasis on efficiency and energy consumption (Inglesi-Lotz and Blignaut, 2011; Markandya et al., 2006; Andrade-Silva and Guerra, 2009; Mendiluce et al., 2010), for carbon emission (Hammond and Norman, 2011; Kumbaroglu, 2011; Sheinbaum et al., 2011), for both emission and energy intensities (Ang and Choi, 1997). However, others have used the techniques for sectoral energy saving estimation and related rebound energy effect (Shaikh et al., 2010).

In addition, most studies in the literature concerning Nigeria are empirical analysis, attempting to relate the energy consumption and economic growth (GDP) only (Odularu and Okonkwo, 2009; Olusegun, 2008). Such analysis is not sufficient for a country like Nigeria with a multifaceted energy planning structure. Presently, the country is facing an imbalance in her domestic energy supply, a situation that has slowed industrialization (Oyedepo et al., 2018). If the current trend in energy is extended, it is evident that the energy scenarios of the country are critical for the long term. Given this situation, it is necessary to understand extensively the methodical breakdown of the structural changes in the economic sectors and energy saving during the past few years. Because energy saving measures a country's adequate energy planning, energy demand forecasting is key for informed energy management and policy decisions to guarantee energy security and tackle climate change. While there have been many studies in different countries focusing on the short and medium term (to 2020 and 2050) there is none in the literature for Nigeria, focusing on the short and medium term. Consequently, this research work seeks to address those gaps on sectoral energy demands in the long term by following the decomposition approach. It develops key energy indicators on useful energy demand, transport mobility and end use fuel demand for various sectors. The main drivers of these indicators are the economic growth, energy consumption, and its associated intensity which will be used in industrial, transportation, and agricultural sectors.

Here, the three-dimension complete decomposition model is formulated to analyse the energy saving and energy rebound effect of different sectors in Nigeria. The study analysed data for the period 1990-2015 to present a framework for forecasting energy consumption patterns in selected sectors of the nation for the years 2016-2050.

2. Materials and methods

2.1 Energy prediction modelling

The method of complete decomposition considers sectoral energy consumption related to the

GDP. This forms the basis of the decomposition. For n sectors, the aggregate energy consumption can be expressed as,

$$E_t = \sum_{i=1}^{n} E_{it} \quad (1)$$

From Equation (1), the total energy consumption from the sectors can be decomposed into three key variables with the established relationships:

Activity effect: This is also called the *GDP*-effect stated as:

$$A_t = \sum_{i=1}^{n} A_{it} \quad (2)$$

where A is the *GDP*.

Intensity effect: This is considered for the i^{th} sector and expressed as:

$$B_{it} = \frac{E_{it}}{A_{it}} \quad (3)$$

Structural effect: This is considered for a sector with reference to the whole sectors as:

$$C_{it} = \frac{A_{it}}{A_t} \quad (4)$$

With Equations (2), (3) and (4), the total energy consumption is decomposed as:

$$E_t = \sum_i A_t B_{it} C_{it} \quad (5)$$

And with the substituted values, the total energy consumption takes the form:

$$E_t = \sum_i A_t B_{it} C_{it} \quad (6)$$

$$E_t = \sum_i A_t \frac{E_{it}}{A_{it}} \frac{A_{it}}{A_t} \quad (7)$$

From equation 5, the effect of GDP, energy intensity, and energy consumption can be written as,

$$E_t = A_{effect} + B_{effect} + C_{effect} \quad (8)$$

Following the decomposition method, each effect can be written in the general form as (Sun, 2001)

$$X_{i-effect} = \frac{\prod_i^n X_i^o}{X_i^o} \Delta X_i + \frac{1}{2} \sum_{j \neq i} \frac{\prod_i^n X_i}{X_j^o X_i^o} \Delta X_j \Delta X_i + \frac{1}{3} \sum_{k \neq j \neq i} \frac{\prod_i^n X_i}{X_k X_j X_i} \Delta X_k \Delta X_j \Delta X_i + \cdots \frac{\prod_i^n \Delta X_i}{n} \quad (9)$$

From Equations (8) and (9), following the refined Laspeyres index method, changes in a parameter with only one changing factor are obviously caused by the changing factor alone. For an effect with two changing items, these changes are divided into two equal parts with the effect distributed evenly between the changing factors. Similarly, the item with three changing variables is divided into three equal parts with the effect distributed evenly among all three factors. Summing all the changes due to the variables, the decomposition result for these three effects are as follows:

$$B_{effect} = \sum_i^n (\Delta B_i) C_i^0 A^0 + \frac{1}{2} \sum_i^n \Delta B_i \left[(\Delta C_i) A^0 + C_i^0 \Delta A \right] + \frac{1}{3} \sum_i^n \Delta B_i \Delta C_i \Delta A \quad (10)$$

$$C_{effect} = \sum_i^n B_i^0 (\Delta C_i) A^0 + \frac{1}{2} \sum_i^n \Delta C_i \left[(\Delta B_i) A^0 + B_i^0 \Delta A \right] + \frac{1}{3} \sum_i^n \Delta B_i \Delta C_i \Delta A \quad (11)$$

$$A_{effect} = \sum_i^n B_i^0 C_i^0 \Delta A + \frac{1}{2} \sum_i^n \Delta A \left[(\Delta B_i) C_i^0 + B_i^0 \Delta C_i \right] + \frac{1}{3} \sum_i^n \Delta B_i \Delta C_i \Delta A \quad (12)$$

2.2 Predicted energy savings model

The predicted energy savings model is derived from the developed expressions and is obtained in Equations (13) and (14) as (Sun, 2003):

$$\psi = B_{effect} + C_{effect} \quad (13)$$

$$\psi = \sum_i^n (\Delta B_i) C_i^0 A^0 + \frac{1}{2} \sum_i^n \Delta B_i \left[(\Delta C_i) A^0 + C_i^0 \Delta A \right] + \frac{1}{3} \sum_i^n \Delta B_i \Delta C_i \Delta A + \sum_i^n B_i^0 (\Delta C_i) A^0 + \frac{1}{2} \sum_i^n \Delta C_i \left[(\Delta B_i) A^0 + B_i^0 \Delta A \right] + \frac{1}{3} \sum_i^n \Delta B_i \Delta C_i \Delta A \quad (14)$$

Energy saving appears mathematically in these models as a negative value of ψ. Thus, the negative values have *B*-effect and *S*-effect, represents the saving caused by the change of the respective dimensions.

2.3 Energy rebound effect

The rebound effect occurs as an improvement of energy efficiency and is expressed as (Berkhout et al., 2000):

$$E_{reb.} = \sum_i^n B_i^0 (\Delta C_i) A^0 + \frac{1}{2} \sum_i^n \Delta C_i \left[(\Delta B_i) A^0 + B_i^0 \Delta A \right] + \frac{1}{3} \sum_i^n \Delta B_i \Delta C_i \Delta A + \sum_i^n B_i^0 C_i^0 A + \frac{1}{2} \sum_i^n \Delta A \left[(\Delta B_i) C_i^0 + B_i^0 \Delta C_i \right] + \frac{1}{3} \sum_i^n \Delta B_i \Delta C_i \Delta A \quad (15)$$

2.4 Energy dematerialisation

This refers to the real change of energy use in an observation year if that is less/more than the trend based on the levels of a given base year, and if this process occurred throughout the whole observation period. It is mathematically expressed as:

$$E_{demat.} = -\sum_i^n (\Delta B_i) C_i^0 A^0 - \frac{1}{2} \sum_i^n \Delta B_i \left[(\Delta C_i) A^0 + C_i^0 \Delta A \right] - \frac{1}{3} \sum_i^n \Delta B_i \Delta C_i \Delta A \quad (16)$$

2.5 Decomposed energy forecast model

The energy forecast model is based on the decomposition model and is expressed as follows (Sun, 2003):
Assume that an examined index A can be decomposed into the product of n factors:
$A = \prod_i^n X_i$ from $t = 0$ to $t = T$, X_i and A have changed from X_i^0 and A^0 to X_i^T and A^T, respectively. X_i and ΔA are increments (i =1,…, n). According to the complete decomposition method, the change of A is equal to the sum of the effects from each factor expressed as:

$$\Delta A = A^T - A^0 = \prod_i^n X_i^T - \prod_i^n X_{i-effect} \quad (17)$$

where the term $X_{i-effect}$ is as obtained from Equation (17). The forecasted energy at a year T can be obtained from Equation (17) as:

$$A^T = \Delta A + A^0 \quad (18)$$

Additionally, since the value of summation of the three effects is same as the term ΔA, then the energy forecast for a year T with reference to the base year is estimated with the expression:

$$A^T = A^0 + \sum_i^n B_i^0 C_i^0 A + \frac{1}{2}\sum_i^n \Delta A\left[(\Delta B_i)C_i^0 + B_i^0 \Delta C_i\right] + \frac{1}{3}\sum_i^n \Delta B_i \Delta C_i \Delta A + \sum_i^n (\Delta B_i) C_i^0 A^0 + \frac{1}{2}\sum_i^n \Delta B_i\left[(\Delta C_i)A^0 + C_i^0 \Delta A\right] + \frac{1}{3}\sum_i^n \Delta B_i \Delta C_i \Delta A + \sum_i^n B_i^0 (\Delta C_i) A^0 + \frac{1}{2}\sum_i^n \Delta C_i\left[(\Delta B_i)A^0 + B_i^0 \Delta A\right] + \frac{1}{3}\sum_i^n \Delta B_i \Delta C_i \Delta A \quad (19)$$

The expression in Equation (19) shall be used to continuously forecast energy consumption per sector. Each forecast shall be referenced on a base year and will cumulatively be a function of the previous years in steps. Other performance indices like the energy rebound, dematerialisation, materialisation and trend, shall be predicted based on the decomposition approach. The parameters for successful forecast depend on known values of changes in structural and GDP for the considered sectors. Expressions for the calculation of structural and GDP changes for a forecasting year are given with the relationships (Sun, 2001):

$$\gamma_i{}^T = \frac{(1+\lambda_i){Q_i}^{T-1}}{\sum_i^n (1+\lambda_i){Q_i}^{T-1}} \Big/ \frac{{Q_i}^{T-1}}{\sum_i^n {Q_i}^{T-1}} - 1 \quad (20)$$

$$\lambda^T = \frac{\sum_i^n (1+\lambda_i){Q_i}^{T-1}}{\sum_i^n {Q_i}^{T-1}} - 1 \quad (21)$$

where the terms $\lambda^T, \gamma_i{}^T, {Q_i}^{T-1}$ represents respectively, the total GDP growth rate, structural growth rate, and the sectoral GDP for a preceding year.

2.6 Index decomposition analysis

If V is an aggregate composed of n factors $(x_1, x_2, \dots . x_n)$ such that from period 0 to T the aggregate changes from V^0 to V^Ti.e. $V = \sum_i V_i$ and $V_i = x_{1,i}, x_{2,i}, \dots x_{n,i}$, then the contributions of the n factors to the change in the aggregate can be expressed as (Ang and Liu, 2001):

$$\Delta V_{TOT} = V^T - V^0 = \Delta V_{x1} + \Delta V_{x2} + \cdots + \Delta V_{xn} \quad (22)$$

2.6.1 Logarithmic mean divisia index method

The general expression for the logarithmic mean divisia index method is expressed as (Ang and Liu, 2001; Ang et al., 2002; Ang, 2005):

$$\Delta V_{xk} = \sum_i L\left({V_{i,}}^T {V_i}^0\right) ln\left(\frac{{x_{k,i}}^T}{{x_{k,i}}^0}\right) \quad (23)$$

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

$$L\left({V_{i,}}^T {V_i}^0\right) = \frac{{V_{i,}}^T - {V_{i,}}^0}{\ln({V_{i,}}^T) - \ln({V_{i,}}^0)} \quad (24)$$

The relative contribution of the terms which constitutes the effects of energy decomposition are expressed with the LMDI method with the relationships expressed below (Ang, 2004; Ang et al., 2003; Ang et al., 2002):

$$\Delta E_{activity} = \sum_i \left(\frac{{E_i}^T - {E_i}^T}{ln[{E_i}^T] - ln[{E_i}^0]}\right) ln\left[\frac{Q^T}{Q^0}\right] \quad (25)$$

$$\Delta E_{intensity} = \sum_i \left(\frac{{E_i}^T - {E_i}^0}{ln[{E_i}^T] - ln[{E_i}^0]}\right) ln\left[\frac{{I_i}^T}{{I_i}^0}\right] \quad (26)$$

$$\Delta E_{structure} = \sum_i \left(\frac{{E_i}^T - {E_i}^0}{ln[{E_i}^T] - ln[{E_i}^0]}\right) ln\left[\frac{S^T}{S^0}\right] \quad (27)$$

The development of the LMDI method is based on Equation (28) which is expressed in terms of the energy consumption as:

$$\Delta E_{TOT} = E^T - E^0 = \Delta E_{x1} + \Delta E_{x2} + \cdots + \Delta E_{xn} \quad (28)$$

The expression in Equation (28) can be altered to the form:

$$\Delta E_{TOT} = \sum_i \left(\frac{{E_i}^T - {E_i}^T}{ln[{E_i}^T] - ln[{E_i}^0]}\right) ln\left[\frac{{E_i}^T}{{E_i}^0}\right] \quad (29)$$

By substituting terms of Equation (7) in (29), and following the nomenclature of the current and reference years, the following expression is obtained:

$$\Delta E_{TOT} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{Q^T S_i{}^T I_i{}^T}{Q^0 S_i{}^0 I_i{}^0}\right] \quad (30)$$

Expanding the natural logarithm term in Equation (30), the following expression is obtained:

$$\Delta E_{TOT} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right)\left(ln\left[\frac{Q_i{}^T}{Q_i{}^0}\right] + ln\left[\frac{S_i{}^T}{S_i{}^0}\right] + ln\left[\frac{I_i{}^T}{I_i{}^0}\right]\right) \quad (31)$$

By expanding Equation (31), the following form of the expression is obtained:

$$\Delta E_{TOT} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{Q_i{}^T}{Q_i{}^0}\right] + \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{S_i{}^T}{S_i{}^0}\right] + \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{I_i{}^T}{I_i{}^0}\right] \quad (32)$$

Comparing terms of Equations (32) and (31), it is seen that the terms for the three effects are obtained as follows:

$$A_{effect} = \sum_i \left(\frac{E_i{}^T - E_i{}^T}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{Q^T}{Q^0}\right] \quad (33)$$

$$B_{effect} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{I_i{}^T}{I_i{}^0}\right] \quad (34)$$

$$C_{effect} = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left[\frac{S^T}{S^0}\right] \quad (35)$$

2.7 Sectoral energy efficiency

The microeconomics of end-use energy saving can be assessed using the concept of energy efficiency and frugality. Frugality refers to the behaviour that is aimed at energy conservation, and with efficiency we refer to the technical ratio between energy input and output services that can be modified with technical improvements (Oikonomou et al. 2009). The energy efficiency is defined as:

$$\boldsymbol{EF} = \frac{\boldsymbol{E_t}}{\boldsymbol{Q_t}} \quad (36)$$

$$\boldsymbol{EF} = \sum_i \frac{\boldsymbol{E_i{}^T}}{\boldsymbol{Q_i{}^T}} \frac{\boldsymbol{Q_i{}^T}}{\boldsymbol{Q^T}} \quad (37)$$

$$\boldsymbol{EF} = \sum_i \boldsymbol{I_i{}^T S_i{}^T} = \Delta \boldsymbol{E_{intensity}} + \Delta \boldsymbol{E_{activity}} \quad (38)$$

$$EF = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left(\left[\frac{I_i{}^T}{I_i{}^0}\right]\left[\frac{Q_i{}^T}{Q_i{}^0}\right]\right) \quad (39)$$

The energy efficiency is calculated for each sector using the expression shown in equation 39, where the GDP and energy intensity has been replaced by $\boldsymbol{Q}$ and $\boldsymbol{I}$ respectively.

3. Results and discussion

3.1 Sectoral energy models

Results from the preliminary data evaluation for the considered sectors is presented. Values for the economic structure were obtained with standard reference to the cumulative gross domestic products of the transportation, industrial, and agricultural sectors. The transportation sector comprised some other sub sectors whose contributions are comparatively small. The energy intensity which stems from the quantity of energy consumption and gross domestic product for the considered years in the agricultural sector fluctuated between 22.37 to 264.3 toe/mill. USD for the years 1998 and 1992 respectively.

In Fig. 1, energy savings from the analysis due to the relationship between GDP and energy input is shown in the course of the considered period for the agricultural sector. Energy savings are shown negative for the years, and reflects a measure of the relative output (GDP) which results from known inputs (energy consumption). The decomposition model levelized all operating data to establish a common ground in terms of the energy units by annulling the variation in GDP during the analysis. As Fig. 1 shows, the trend of savings is observed down the negative x-axis. This representation presents the annual energy savings for the years 1993-1998, 2005, 2006, 2009, and 2010 where the energy input gave more of an equivalent gross domestic unit. However, the years 1991, 1992, 1999 – 2004, as well as 2007, 2008 and 2011 did not record any energy savings.

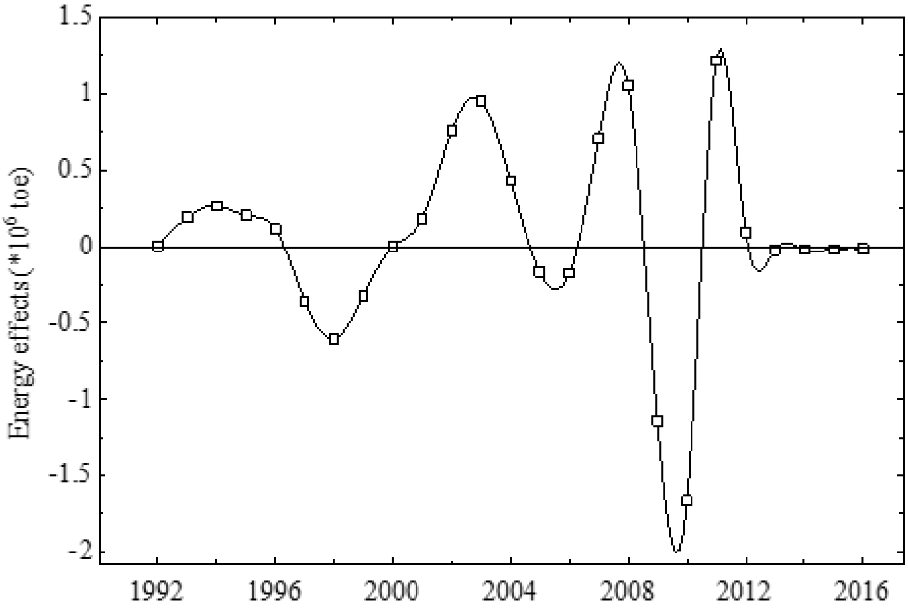

Fig. 1: Energy savings in the agricultural sector for the years

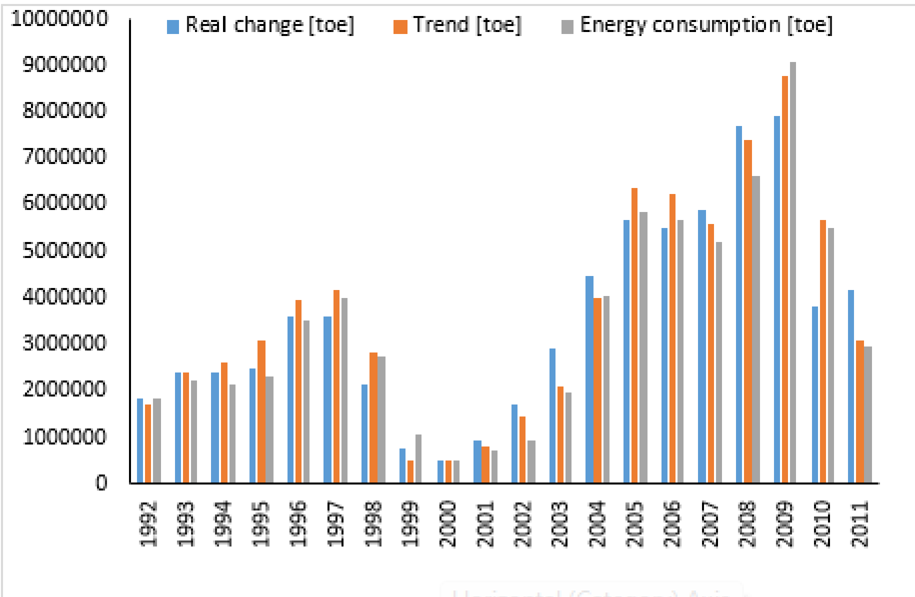

Fig. 2: Energy trend, consumption and real changes (agricultural sector)

Changes in energy consumption, both in terms of the trend and gross domestic products represents variations in the energy mix, directly relating the dynamics of the decomposition model. This relationship is shown in Fig. 2, where the energy trend, consumption and real changes are shown. The 'real change' represents the changes in energy consumption plus variation in energy for a previous year, and characterises the prediction strength of the 3-D modelling approach. With very accurate changes in energy consumption, especially with economic structure referenced within the agricultural sector, the real changes is found useful for forecasting of consumption patterns in the short and long term.

Furthermore, the energy consumption trend which relates the relative contributions of the gross domestic products (decomposed to energy units) to gross energy savings, is shown for the years under consideration. The trend compares well with the energy savings over the years 1992 to 1997 where they were energy savings, while the relatively poor GDP in the years 2006 to 2011 results in lower trends than the corresponding energy consumption.

3.2 Industrial sector

The changes in energy consumption which were observed in the industrial sector are presented in Fig. 3. The energy intensity which stems from the quantity of energy consumption and gross domestic product for the considered years fluctuated between 437 to 1468.5 toe/mill. USD for the years 2010 and 1992 respectively. As shown in Fig. 4, the trend of the savings is observed down the negative x-axis. This representation presents the annual energy savings for the years 1993, 1994, 1996-1998, 2001, 2002, 2005, and then 2005-2010 where the energy input gave more of an equivalent gross domestic unit. However, the years other than the ones mentioned in the range of 1991 to 2011 did not record any energy savings.

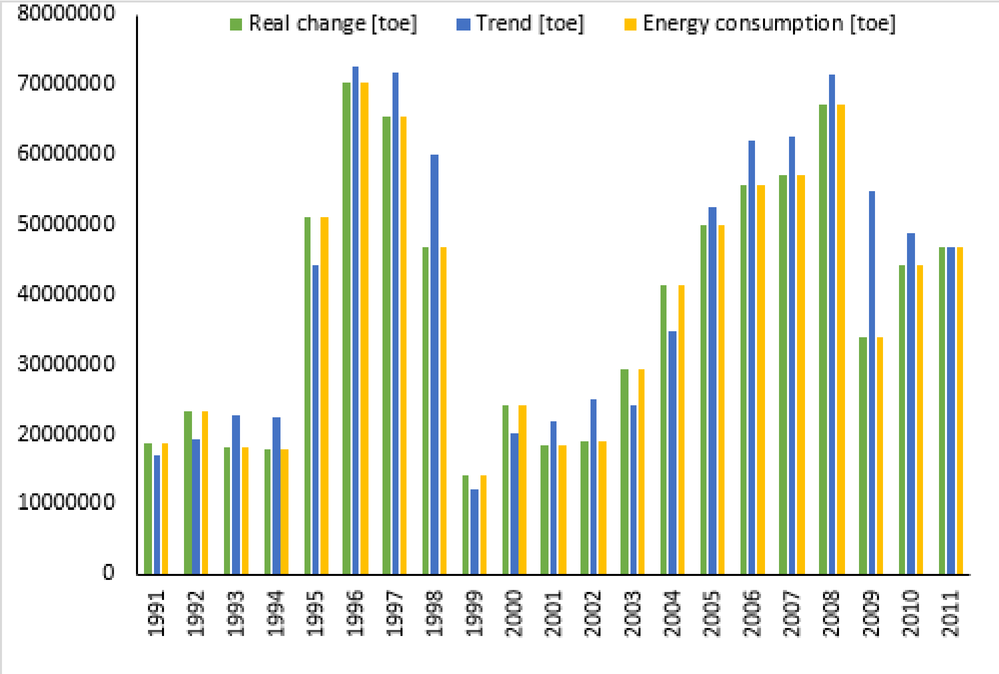

Fig. 3: Energy trend, consumption and real changes (industrial sector)

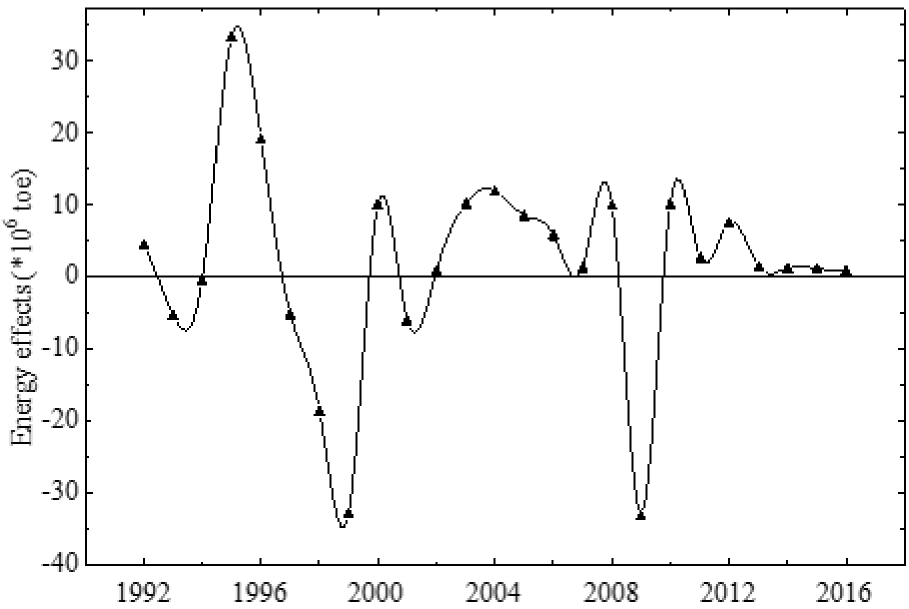

Fig. 4: Energy savings in the industrial sector for the years

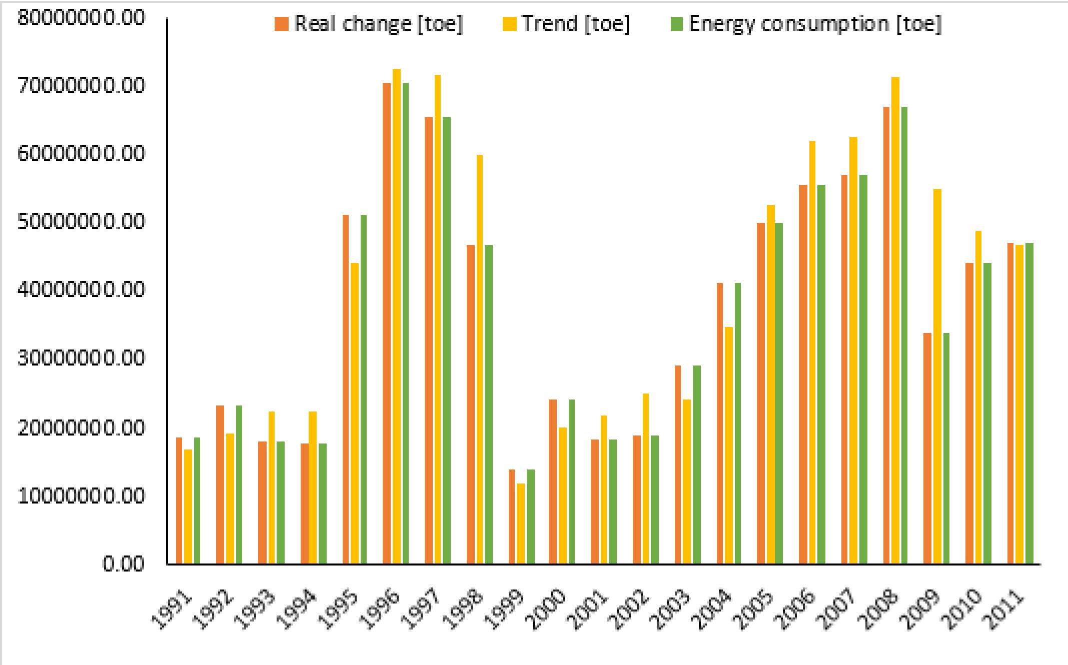

Fig. 5: Energy trend, consumption and real changes (transport sector)

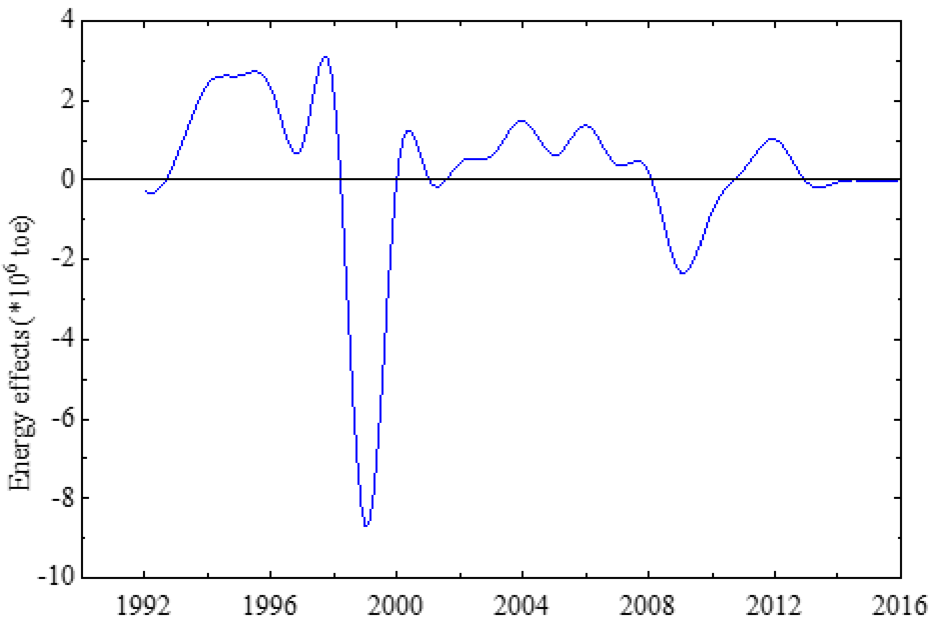

Fig. 6: Energy savings in the transportation sector for the years

3.3 Medium term sectoral energy prediction

For the considered sectors, energy forecast is made in the light of the decomposition model with predicted structural and GDP changes. The prediction strength of the decomposition model is made by comparison of actual data with the virtual data. Predictions were made from 2017 through 2050. Similarly, projections are made for the other years across the sectors with results presented in Tables 1 to 4.

Table 1: Transportation sector energy forecast

Year	Energy consumption [toe]	Sectoral GDP [Million USD]	Energy intensity [toe/million USD]
2012	6728000	4705.7	1429.755
2013	6675000	5098.1	1309.311
2014	6624000	5477.7	1209.267
2015	6594000	5836.2	1129.845
2016	6598000	6168.6	1069.611
2017	6642000	6472.6	1026.172
2018	6727000	6748.1	996.8732
2019	6852000	6996.4	979.3608
2020	7012000	7219.7	971.2315
2021	7202000	7420.2	970.5938
2022	7419000	7600.3	976.1457
2023	7656000	7762.2	986.3183
2024	7911000	7907.9	1000.392
2025	8179000	8038.9	1017.428
2026	8459000	8156.8	1037.049
2027	8747000	8262.8	1058.6
2028	9042000	8357.9	1081.851
2029	9342000	8443.2	1106.453
2030	9646000	8519.3	1132.253
2031	9953000	8587.2	1159.051
2032	10261000	8647.4	1186.599
2033	10571000	8700.5	1214.988
2034	10882000	8747.1	1244.069
2035	11192000	8787.8	1273.584
2036	11503000	8823	1303.752
2037	11813000	8853	1334.35
2038	12122000	8878.4	1365.336
2039	12431000	8899.5	1396.82
2040	12738000	8916.5	1428.587
2041	13045000	8929.9	1460.823
2042	13350000	8940	1493.289
2043	13653000	8946.8	1526.02
2044	13955000	8950.8	1559.079
2045	14256000	8952.2	1592.458
2046	14554000	8951.1	1625.945
2047	14851000	8947.7	1659.756
2048	15145000	8942.3	1693.636
2049	15438000	8934.9	1727.831
2050	15728000	8925.7	1762.103

Table 2: Agricultural sector energy forecast

Year	Energy consumption [toe]	Sectoral GDP [Million USD]	Energy intensity [toe/million USD]
2012	5726400	89960	63.65496
2013	5623900	99380	56.58986
2014	5514000	108520	50.81091
2015	5408900	117140	46.17466
2016	5316600	125050	42.51579
2017	5241300	132100	39.67676
2018	5184300	138230	37.50488
2019	5144800	143410	35.87476
2020	5120400	147680	34.67226
2021	5108600	151120	33.80492
2022	5106400	153800	33.20156
2023	5111100	155840	32.7971
2024	5120100	157340	32.54163
2025	5131500	158410	32.39379
2026	5143600	159150	32.3192
2027	5155200	159640	32.29266
2028	5165500	159950	32.29447
2029	5173900	160160	32.30457
2030	5180200	160310	32.31364
2031	5184200	160450	32.31038
2032	5186100	160600	32.29203
2033	5186100	160800	32.25187
2034	5184500	161070	32.18787
2035	5181500	161410	32.10148
2036	5177500	161820	31.99543
2037	5172800	162330	31.86595
2038	5167800	162910	31.72181
2039	5162800	163580	31.56132
2040	5158000	164320	31.38997
2041	5153700	165140	31.20807
2042	5150100	166010	31.02283
2043	5147300	166940	30.83323
2044	5145500	167920	30.64257
2045	5144900	168940	30.45401
2046	5145400	169990	30.26884
2047	5147200	171060	30.09003
2048	5150300	172160	29.91578
2049	5154700	173260	29.75124
2050	5160300	174380	29.59227

Table 3: Industrial sector energy forecast

Year	Energy consumption [toe]	Sectoral GDP [Million USD]	Energy intensity [toe/million USD]
2012	54540000	114050	478.2113
2013	55998000	123350	453.9765
2014	57281000	131660	435.0676
2015	58410000	139030	420.1252
2016	59409000	145500	408.3093
2017	60299000	151180	398.8557
2018	61102000	156140	391.3283
2019	61835000	160490	385.2888
2020	62512000	164310	380.4516
2021	63146000	167670	376.6088
2022	63746000	170630	373.592
2023	64321000	173240	371.2826
2024	64877000	175540	369.5853
2025	65419000	177580	368.3917
2026	65952000	179380	367.6664
2027	66480000	180980	367.3334
2028	67004000	182390	367.3666
2029	67528000	183640	367.7195
2030	68054000	184750	368.3572
2031	68583000	185730	369.2618
2032	69117000	186600	370.4019
2033	69656000	187360	371.7763
2034	70201000	188040	373.3301
2035	70754000	188640	375.0742
2036	71315000	189170	376.989
2037	71884000	189640	379.0551
2038	72461000	190060	381.2533
2039	73047000	190420	383.6099
2040	73642000	190740	386.0858
2041	74246000	191030	388.6615
2042	74859000	191280	391.3582
2043	75481000	191500	394.1567
2044	76111000	191690	397.0525
2045	76750000	191860	400.0313
2046	77397000	192010	403.0884
2047	78052000	192150	406.2035
2048	78713000	192260	409.4091
2049	79382000	192370	412.6527
2050	80058000	192460	415.9722

Table 4: Aggregate energy and GDP forecast

Year	Energy consumption [toe]	GDP [Million USD]	Energy intensity [toe/million USD]
2012	66994400	208715.7	320.984
2013	68296900	227828.1	299.7738
2014	69419000	245657.7	282.5843
2015	70412900	262006.2	268.7452
2016	71323600	276718.6	257.7478
2017	72182300	289752.6	249.117
2018	73013300	301118.1	242.474
2019	73831800	310896.4	237.4804
2020	74644400	319209.7	233.8413
2021	75456600	326210.2	231.3128
2022	76271400	332030.3	229.7122
2023	77088100	336842.2	228.8552
2024	77908100	340787.9	228.6117
2025	78729500	344028.9	228.8456
2026	79554600	346686.8	229.4711
2027	80382200	348882.8	230.3989
2028	81211500	350697.9	231.5711
2029	82043900	352243.2	232.9183
2030	82880200	353579.3	234.4034
2031	83720200	354767.2	235.9863
2032	84564100	355847.4	237.6415
2033	85413100	356860.5	239.3459
2034	86267500	357857.1	241.0669
2035	87127500	358837.8	242.8047
2036	87995500	359813	244.559
2037	88869800	360823	246.2975
2038	89750800	361848.4	248.0343
2039	90640800	362899.5	249.7683
2040	91538000	363976.5	251.4943
2041	92444700	365099.9	253.2038
2042	93359100	366230	254.9193
2043	94281300	367386.8	256.6268
2044	95211500	368560.8	258.3332
2045	96150900	369752.2	260.0415
2046	97096400	370951.1	261.7499
2047	98050200	372157.7	263.4641
2048	99008300	373362.3	265.1802
2049	99974700	374564.9	266.9089
2050	100946300	375765.7	268.6416

Results from forecast of energy consumption, GDP, and the corresponding energy intensity are shown in Tables 1, 2, 3, and 4 for the transport sector, agricultural sector, industrial sector, and its corresponding aggregate. The prediction is made based on previous energy changes for preceding years at increasing energy demand. Under this condition, the increase in energy demand at the end of 2020 will have risen to 74644400 toe. Nevertheless, the effect of dematerialization will produce a decrease of 1244562.57 toe. Consequently, the real increase in energy demand will be 75888962.52 toe, which will be an increase of 6.40 % when compared to 2016. When compared to the forecast peak, an increase in energy demand will rise up to 100946300 toe with materialization pushing the consumption by 658772.339 toe to approximately 101605072.3 toe, which represents a relatively high 42.46 % increase in energy consumption demand at 2050 with reference to 2016.

3.4 Index decomposition analysis of energy consumption

Index decomposition of energy consumption for past and projected years is presented to determine energy efficiency improvement and contribution to reduction in consumption via dematerialization. Changes in activity, structure and intensity effects are shown using the LMDI methods in Fig. 7 for past and projected years. Computations have been made for the sectors with the results presented accordingly.

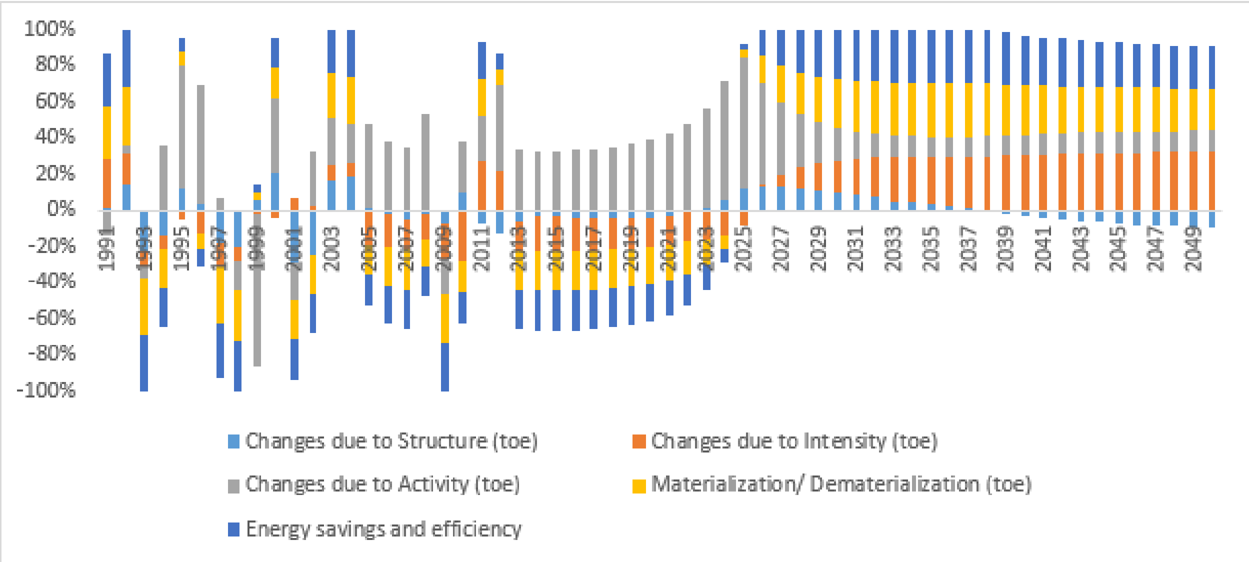

Fig. 7: Index decomposition of energy consumption

Table 5: Index decomposition of energy consumption

Year	Changes due to Structure (toe)	Changes due to Intensity (toe)	Changes due to Activity (toe)	Materialization/ Dematerialization (toe)	Energy savings and efficiency
1991	123336.4	2251777.556	-1125115.49	2375113.98	2375113.98
1992	1847918	2250690.667	552132.4026	4098608.422	4098608.42
1993	-2750311	-1093138.848	-820602.645	-3843450	-3843450.00
1994	-2106414	-1138718.505	5329320.671	-3245132.25	-3245132.25
1995	6042076	-2471159.053	33753600.12	3570917.172	3570917.17
1996	1383673	-4940773.493	25564001.51	-3557100.2	-3557100.20
1997	-4026088	-2994107.729	1595892.601	-7020196.01	-7020196.01
1998	-8204210	-3160934.117	-6651257.85	-11365144.5	-11365144.46
1999	3126729	-938190.7578	-44252358	2188538.184	2188538.18
2000	3843916	-791368.3734	7324728.334	3052547.223	3052547.22
2001	-3757673	826484.5585	-2752558.02	-2931188.84	-2931188.84
2002	-6901386	729799.691	8418049.462	-6171586.19	-6171586.19
2003	4130458	2137853.042	6614656.723	6268310.643	6268310.64
2004	6037787	2318220.719	6940943.678	8356007.804	8356007.80
2005	552627.3	-5904233.881	14338118.4	-5351606.6	-5351606.60

2006	-643656	-7618301.574	15008492.39	-8261957.08	-8261957.08
2007	-1338763	-4072666.37	8559055.879	-5411429.33	-5411429.33
2008	-603207	-4789028.395	18048544.86	-5392235.12	-5392235.12
2009	-6175288	-16917246.6	-15862820.94	-23092534.4	-23092534.41
2010	6668282	-18002018.12	18212505.18	-11333735.7	-11333735.71
2011	-892525	3532606.517	3241641.323	2640081.628	2640081.63
2012	-996793	1694425.468	3702024.031	697632.3251	697632.33
2013	-1589399	-4131613.398	8845475.162	-5721012.02	-5721012.02
2014	-513687	-3537973.22	6040553.708	-4051660.56	-4051660.56
2015	-550289	-2993068.141	5276665.574	-3543356.94	-3543356.94
2016	-537591	-2484596.276	4574176.057	-3022187.58	-3022187.58
2017	-492760	-2041354.255	3926884.805	-2534114.42	-2534114.42
2018	-414256	-1643577.705	3346209.654	-2057833.84	-2057833.84
2019	-326423	-1305875.677	2827977.64	-1632298.28	-1632298.28
2020	-226289	-1018273.792	2374008.555	-1244562.57	-1244562.57
2021	-129847	-772069.888	1981108.578	-901916.594	-901916.59
2022	-43783.5	-560561.5531	1645949.897	-604345.031	-604345.03
2023	35034.87	-381535.8826	1356078.222	-346501.008	-346501.01
2024	96878.39	-225722.4665	1115210.921	-128844.073	-128844.07
2025	145525.3	-98244.1905	912403.9062	47281.15668	47281.16
2026	180802.7	17595.15695	749629.5978	198397.872	198397.87
2027	200945.5	112700.9979	616100.0328	313646.4855	313646.49
2028	212452.3	199546.9563	510913.1754	411999.2489	411999.25
2029	212920.6	272874.7469	424319.7817	485795.333	485795.33
2030	202972.2	337732.7012	363230.7686	540704.8678	540704.87
2031	188530	396257.3415	315944.5825	584787.3019	584787.30
2032	166348.1	446692.6421	282652.1852	613040.7808	613040.78
2033	112118.9	535047.3815	244226.1346	647166.2422	647166.24
2034	112118.9	535047.3815	244226.1346	647166.2422	647166.24
2035	81100.98	573327.6364	241872.2457	654428.6173	654428.62
2036	50229.31	610219.1852	239661.9273	660448.4913	660448.49
2037	20604.81	640771.0179	240006.4335	661375.8258	661375.83
2038	-14369.5	668602.4221	250351.4584	654232.9296	654232.93
2039	-41451.9	701981.6289	255995.3504	660529.7546	660529.75
2040	-74476.4	726746.0133	264319.3428	652269.5973	652269.60
2041	-100753	749347.5561	272783.0833	648594.3436	648594.34
2042	-127843	774899.613	286568.995	647056.3434	647056.34
2043	-149691	796768.5353	290315.3399	647077.7503	647077.75
2044	-172893	818737.6783	299264.2985	645844.6049	645844.60
2045	-193615	838292.8177	305829.8545	644677.43	644677.43
2046	-210753	855148.9339	312486.2284	644396.128	644396.13
2047	-225761	870445.2722	316583.4137	644684.1355	644684.14
2048	-236995	889286.0169	320733.7806	652291.4099	652291.41
2049	-253337	901030.6585	322371.7516	647693.9671	647693.97
2050	-258376	917148.451	323922.1428	658772.339	658772.34

Energy efficiency improvement contribution is shown with the effect of energy intensity as negative while the activity effect, which characterizes reduction in energy consumption, is observed for a couple of years. The years 1993 through 2000 are reflective of higher energy efficiency with minimal contribution in energy consumption reduction from structural changes in GDP at sectoral level. Energy efficiency values are particularly noteworthy throughout between 2017 and 2024. If the trend of energy consumption and GPD are fashioned according to the forecasted results, serious economic policies must be initiated and implemented to salvage it. Furthermore, overall contribution of aggregate activity effect to reduction in energy consumption is comparatively small resulting from limited number of exports. This trend is not remedied from the forecasted result and can be tackled through development of local content to improve aggregate activity effect in energy efficiency. Values for materialization and dematerialization are also presented. It is important to note that the dematerialisation which grossly reduces energy consumption is a function of the economic effect due to GDP changes. Between 2024 and 2050, the projected results show materialisation of energy consumption. This is responsible for insufficient energy savings between these periods.

4. Conclusion

Forecast on sectoral energy saving and consumption in Nigeria using the 3-D decomposition and LMDI approach has been considered. With energy consumption, gross domestic product, and energy intensity from industrial, transportation and agricultural sectors, energy consumption was projected up to 2050 to study the energy efficiency trend, savings and dematerialisation. The model application indicates that the aggregate energy demand in Nigeria by the end of 2050 will increase from 75323176 to 99974700 toe compared to the 2015 level. Consequently, energy materialisation is expected to increase from 47281.15 to 658772.33 toe between 2025 and 2050. The country had an energy over-consumption of 129821445.35, 16285998.43, 6342692.71 toe for industrial, transport and agricultural sectors, respectively, during 1990 to 2011. The industrial sector is the major player in the country requiring emphasis in the energy conservation plan. For proper policy recommendation and implementation, it is strongly recommended that a detailed study of the sub-sectors be considered using appropriate index decomposition analysis method.

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