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Evaluation of Intensity and Structural Effects on Energy Consumption Trend in Nigeria Using the 3-D Decomposition Model

Fidelis I. Abam [a], Samuel O. Effiom [b]

[a] Department of Mechanical Engineering, Michael Okpara University of Agriculture, P. M. B 7276, Umuahia, Nigeria
[b] Department of Mechanical Engineering, Cross River University of Technology, P.M.B 1122, Calabar, Nigeria

* Corresponding author. Tel.: +2348166170895;
E-mail address: oliver.lytleton@yahoo.com

A b s t r a c t

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The optimal utilization of energy resources is a hallmark of sustainable growth in both developed and developing economies of the world. Equally, the level of interactions between the economic indicators and how they affect energy consumption (EC) need to be aptly understood. The latter will create an effective structure to balance EC and its attendant ecological consequences. For this reason, the influence of economic indicators: intensity, structural and the energy rebound effect on EC pattern in Nigeria is studied. This includes the agricultural, transportation, and the industrial sectors. The 3-D decomposition technique was adopted using data from 1991 to 2011. Results obtained shows slight energy savings in the agricultural sector, however, the transportation sector witnessed surplus in EC climaxed by the intensity effect. Likewise, the rebound effect, in the agricultural and transportation sectors increased by 18.42 and 86.81 fold respectively, while the industrial sector decreased by 41 fold. Hence, energy conservation measures and technical improvements were most apparent. The study thus suggests, changes arising from the industrial and product structure should be linked with strategic modification of the economic structure. Sector-wise application of these changes will enhance energy efficiency, socio-economic development as well as a reduction in environmental pollution.

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1. Introduction

The subjects of energy efficiency and security are important to a country like Nigeria with fast-depleting energy resources. This will enhance a sustained economic growth especially in the constrained global eco-friendly agreement condition [1]. Optimal utilization of energy resources through a sustainable energy mix structure is viewed as an effective measure to ensure energy security [1]. At the moment, Nigeria seems to have fallen into the whirlpool of energy and power crisis. A condition that has created economic imbalance and consequently slowed industrialization [2]. In confronting the country's energy challenges of production, demand, consumption, and associated environmental problems, the government in the last decades has put in place structural and fiscal policies across the sectors of the economy. The policies were envisioned at providing sustainable energy conservation frameworks to improve efficiency in all the sectors [3-5]. The specific objectives of the

framework include (a) decrease in energy intensity in industries, through applicable energy conservation system, and (b) the integration of greener energy resources like biomass, solar and the wind into the overall energy mix. Studies regarding sectoral performance and EC based on economic characteristics in Nigeria are limited in the open literature. The available studies were that of [6-9] which considered one-dimensional effect (activity) on energy consumption trend only. Additionally, Nigeria with a complicated energy development structure needs a wider analysis in this respect. It is apparent if the current energy trend is protracted, the country's energy settings for long-term scenario will be critical. Given this situation, a methodical breakdown of the structural changes in the economic sectors, as well as the energy consumption (EC) in the past years, needs to be adequately understood. The objectives of this study, therefore, are to evaluate the impact of structural and intensity changes as well as the energy rebound effect on EC in three economic sectors of Nigeria (Agricultural, Industrial, and the Transportation). Moreover, to achieve all these objectives, the study was considered under the following subheadings. First a review of Nigeria economy (section 1.1), methodology and model formulation (section 2) and finally the results and discussion in section 3.

1.1. The Nigeria Economy

The economy of Nigeria depends mainly on oil that contributes about 98 and 80 % of the country's export earnings and government income respectively. The country witnessed a GDP growth rate of 6.9 % between 2005 and 2012, rising to 8.6 % in 2010. However, the GDP declined to 4.5 % in the first quarter of 2009 due to review in the economic policies. In 2011, the GDP was estimated at $US 235.95 billion equivalent to 0.38 % of the global economy [10]. The share of the industrial, agricultural and transportation sector to the overall GDP was 56.28 %, 2.64% and 41.07 % in 1991, respectively while in 2011 the share stood at 57.23 % industrial, 1.99 % agricultural and 40.78 % transportation. The GDPs for the three economic sectors at the 2005 current prices is presented in Figure1 [10].

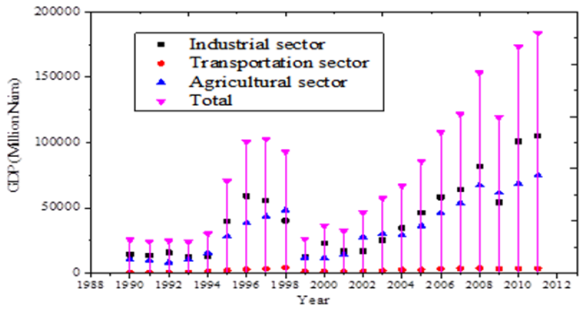

Fig.1: GDP by sector based on 2005 Current Basic Prices from 1990-2011 [10-12]

Furthermore, the analysis of the probable energy reserve in 2011 was: coal 2.7 billion tons, crude oil 37.2 billion barrels and natural gas 5.1 trillion cubic meters. The total energy consumption (EC) in 2011 was calculated at 3.6 % over that in 2010 bringing the value of the aggregate consumption to approximately 4.4 quadrillions [11-12]. The energy consumption profile for the three economic sectors of Nigeria, industrial, agricultural and transportation is presented in Figure 2. The industrial sector witnessed an increase in energy usage from 2002 to 2008 and declined in 2009 and then increased slightly by 2011. The transportation sector fared to drop its share to the nation's EC from 10.12 % in 2008 to 9.76 % in 2011. Lastly, energy usage in the agricultural sector did not exceed 2.5 % in 2000, 7.5 % in 2006 but increase to 10.0 % in 2011.

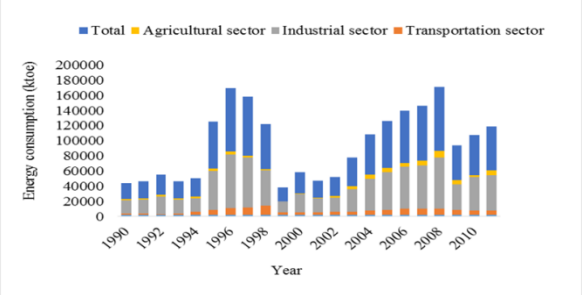

Fig. 2: Energy consumption by sector from 1990-2011 [10], [11], [12]

Also, the energy intensity (EI) from (1991-2011) Figure 3 show that all the sectors experienced fluctuation in EI over the years. EI is the amount of energy units needed to yield one dollar unit of economic output. The EI of the industrial sector improved from 1256.25 ktoe/US$-1000 in 1990 to 1375.30 ktoe/US$-1000 in 1994. Representing a growth of 8.7 % and contributing nearly 27.8 % to the overall EI. The EI dropped by about 30 % from 2006 to 2011. The EI values for the transportation and the agricultural sector decreased by 14.84 % and 12.04 %, respectively from 2009 to 2011. Nonetheless, the contribution of the sectors to the overall EI was 3.7 %, 74.87 %, and 21.39 % for agricultural, transportation and the industrial sectors respectively.

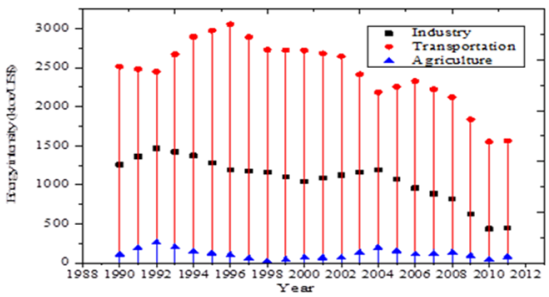

Fig. 3: Energy intensities by sector from 1990-2011 (Authors calculation)

2.0. Methodology and Model Formulation

The net data used for the three sectors (industrial, agricultural and transportation) were obtained from [10-12], for the period between 1991 and 2011. Also, the trend of the EC in each year was modeled based on the GDP_{effect} with the EC at the base year. Values of the GDP and the energy consumption of 1990 were used as the base year inputs. The complete decomposition technique was applied which entails the decomposition of the energy consumption (EC) into three terms of activity (GDP), energy intensity, and economic structure. The decomposition of EC for α economic sector as retrieved from [13-14] is presented in Eq. (1).

$$EC = \sum_i^{\alpha} GDP\, I_i S_i \quad (1)$$

Where, I_i and S_i are the energy intensity and economic structure for sector i, respectively. From Eq. (1) the change in EC for y years can be expressed as,

$$\Delta EC = EC^{y} - EC^{0} = \sum_i^{\alpha} I_i^{y} S_i^{y} GDP^{y} - \sum_i^{\alpha} I_i^{0} S_i^{0} GDP^{0} \quad (2)$$

Where, EC^0 and EC^y are the energy consumption for the base year and y year respectively. The ΔEC is divided into the following influencing indicators: S_{effect}, GDP_{effect} and I_{effect} and rewritten as in Eq. (3)

$$\Delta EC = I_{effect} + S_{effect} + GDP_{effect} \quad (3)$$

Where, S_{effect}, GDP_{effect}, I_{effect} denotes structural effect, activity effect (GDP) and the intensity effect. The three effects are further decomposed into expressions (4) to (6) following the method in (Sun 2001).

$$I_{effect} = \sum_i^{\alpha} \Delta I_i {S_i}^0 GDP^0 + \frac{1}{2}\sum_i^{\alpha} \Delta I_i \left(I_i GDP^0 + {S_i}^0 \Delta GDP\right) + \frac{1}{3}\sum_i^{\alpha} \Delta I_i \Delta S_i \Delta GDP \quad (4)$$

$$S_{effect} = \sum_i^{\alpha} I_i^0 \Delta S_i GDP^0 + \frac{1}{2}\sum_i^{\alpha} \Delta S_i (\Delta I_i GDP^0 + I_i^0 \Delta GDP) + \frac{1}{3}\sum_i^{\alpha} \Delta I_i \Delta S_i \Delta GDP \quad (5)$$

$$GDP_{effect} = \sum_i^{\alpha} I_i^0 S_i \Delta GDP^0 + \frac{1}{2}\sum_i^{\alpha} \Delta GDP (\Delta I_i S_i + I_i^0 \Delta S_i) + \frac{1}{3}\sum_i^{\alpha} \Delta I_i \Delta S_i \Delta GDP \quad (6)$$

2.1. Real and Trend Energy Consumption

The real EC in each sector at any given year y expressed in Eq. (7). The trend of the EC in y year is modeled based on $\mathrm{GDP_{effect}}$ with the EC at the base year just before the year, y Eq. (8). The difference existing between the real and trend of EC is energy saving ψ [16] expressed in Eq. (9). A negative value of ψ connotes less EC while a positive value indicates surplus in EC

$$\mathrm{EC}_{real} = \Delta\mathrm{EC} + \mathrm{EC}^0 \quad (7)$$

$$\mathrm{EC_{trend}} = \mathrm{GDP_{effect}} + \mathrm{EC}^0 \quad (8)$$

$$\psi = \mathrm{Real} - \mathrm{Trend} = \Delta\mathrm{EC} - \mathrm{GDP_{effect}} = \mathrm{I_{effect}} + \mathrm{S_{effect}} \quad (9)$$

In addition, energy saving (ES) and reduction in EC exist for $\psi < 0$ while for $\psi > 0$, ES is not achieved and denotes increase in EC. Consequently Eq. (9) can be expressed in the expanded form by substituting Eqs. (4) and (5) into Eq. (9) as follows,

$$= \sum_i^{\alpha} \Delta\mathrm{I_i}\mathrm{S_i}^0\mathrm{GDP}^0 + \frac{1}{2}\sum_i^{\alpha} \Delta\mathrm{I_i}\,(\mathrm{S_i GDP}^0 + \mathrm{S_i^0}\Delta\mathrm{GDP}) + \sum_i^{\alpha} \mathrm{I_i^0}\Delta\mathrm{S_i GDP}^0 + \frac{1}{2}\sum_i^{\alpha} \Delta\mathrm{S_i}(\Delta\mathrm{I_i GDP}^0 + \mathrm{S_i^0}\Delta\mathrm{GDP}) + \frac{2}{3}\sum_i^{\alpha} \Delta\mathrm{I_i}\Delta\mathrm{S_i}\Delta\mathrm{GDP} \quad (10)$$

2.2. Rebound Energy Effect

The rebound energy effect (RE) predicts the growth that occurs if the technological modification is not included directly. RE also evaluates the response of the sectors regarding EC to the progress of value addition and the structural effect. The decomposition breakdown has been related to sustainability, where dematerialization of the energy production, the materialization of the energy consumption and the rebound energy effect are considered significant in determining energy sustainability. The equation describing energy sustainability [15] is expressed in Eq. (11).

$$\mathrm{E_s} = \begin{pmatrix} \mathrm{E_{De}} \\ \mathrm{E_{Sa}} \\ \mathrm{E_{Re}} \end{pmatrix} = \begin{pmatrix} -1 & 0 & 0 \\ -1 & -1 & 0 \\ 0 & 1 & 1 \end{pmatrix} \begin{pmatrix} \mathrm{I_{effect}} \\ \mathrm{S_{effect}} \\ \mathrm{GDP_{effect}} \end{pmatrix} \quad (11)$$

Where, $\mathrm{E_{De}}$ represents dematerialization, $\mathrm{E_{Sa}}$ is energy saving (immaterialization) and E_{Re} is the rebound energy effect. Solving Eq. (11) yields the solution of the matrix as,

$$\mathrm{E_s} = \begin{pmatrix} \mathrm{E_{De}} \\ \mathrm{E_{Sa}} \\ \mathrm{E_{Re}} \end{pmatrix} = \begin{pmatrix} -\mathrm{I_{effect}} \\ -\mathrm{I_{effect}} - \mathrm{S_{effect}} \\ \mathrm{S_{effect}} + \mathrm{GDP_{effect}} \end{pmatrix} \quad (12)$$

3. Results and discussion

3.1. The Agricultural Sector

Table 1 shows the yearly breakdown of the calculated economic indicators, trend and the real EC from 1991 to 2011 for the agricultural sector. During this period, the overall intensity and structural effects were 834.66 and 2665.65 ktoe respectively. Between the years 1991 and 1992 the intensity effect was responsible for the surplus in EC while the structural effect was the reason for reduction EC. A careful study of Table 1 indicates that during 1993 to 1997 the sector conserved energy climaxed by the intensity effect. Similarly, between these years the structural effect had caused the over-consumption of energy. The changes in $\mathrm{I_{effect}}$ and $\mathrm{s_{effect}}$ were responsible for about 40 % of the energy conserved during this period (1994 to 1998) with values ranged between $363 \leq \mathrm{I_{effect}} \leq 900$ ktoe and $159 \leq \mathrm{S_{effect}} \leq 1260$ ktoe, respectively. Consequently, in 2004 and 2005 the sector observed a marginal decrease of 0.3 % in EC. This reduction in EC is attributed to the policy change in 2005. The variations in EC observed between years in the agricultural sector indicates incongruity in policy implementation. Nonetheless, the agricultural sector is characterized by high energy expenditure since production

methods are subsistent described by high human input intensity with little-mechanized practice.

Table 1: Changes in energy and structural effects on energy consumption in the Agricultural Sector of Nigeria (1991-2011) (ktoe)

Year	I_{effect}	S_{effect}	Real Change	Trend
1991	781.34	-18.47	1843.44	1080.565
1992	701.31	-372.21	2218.95	1889.845
1993	-565.80	569.76	2148.53	2144.567
1994	-783.17	409.88	2297.74	2671.029
1995	-307.73	-535.99	1705.98	2549.700
1996	-583.02	-154.72	2908.35	3646.096
1997	-1660.00	356.83	2739.53	4044.705
1998	891.82	396.66	1080.61	2551.947
1999	245.56	-156.24	1710.21	974.625
2000	538.95	-233.64	731.83	719.907
2001	680.76	2710.00	3894.27	644314
2002	1690.00	365.21	1438.36	1065.066
2003	1910.00	-362.98	3355.36	2028.339
2004	-1260.00	-900.16	5834.20	4820.362
2005	-1590.00	-185.68	4535.11	5978.783
2006	520.00	478.31	4241.31	5784.482
2007	599.00	166.16	5958.13	5271.627
2008	-3320.00	-348.92	7385.38	6821.598
2009	-2550.00	1330.00	6892.37	8886.370
2010	2450.00	-972.52	2128.41	5648.933
2011	2445.64	124.36	5556.53	2982.162
1991-2011	834.66	2665.65	70604.60	72205.022

3.2. The Industrial Sector

The effects of the structural and intensity indicators, as well as the trend and real EC for the industrial sector, is presented in Table 2 from 1991 to 2011. The values exist at 30340 ktoe for I_{effect} and 47661 for $S_{effect.}$ The EC trend during these years are greater than the real EC values in some years indicating less EC. In addition, from 2002 to 2008 the sector witnessed an over consumption which accounted for over 20 % of the total energy consumption in this period. The surplus EC was triggered by the structural effect while the intensity effect has led to reduction in EC. The fluctuations in the sector performance are attributed to

unfavorable fiscal policies, which has stirred increased importation of goods at the detriment of local production. Also, the collapsed in most energy consuming industries like cement, steel and paper industries, was the major factor responsible for decrease in EC. In 2004 and 2005 some economic measures were introduced by government intended at improving the sector performance. These measures are presumed for the marginal success in the economic structure and the intensity between 2005 and 2010.

Table 2: Changes in energy and structural effects on energy consumption in the Industrial Sector of Nigeria (1991-2011) (ktoe)

Year	I_{effect}	S_{effect}	Real Change	Trend
1991	1500.00	191.25	18783.05	17096.80
1992	1570.00	2490.00	23323.09	19258.09
1993	-668.55	-3770.00	18185.79	22625.34
1994	-604.60	-4050.00	17724.46	22381.05
1995	1470.00	5970.00	24880.37	20377.37
1996	-3800.00	1940.00	51494.63	53360.63
1997	-821.00	-5560.00	65408.62	71786.75
1998	-684.00	-12400.00	46876.88	59990.64
1999	-2420.00	5470.00	46441.51	43389.51
2000	-1040.00	5150.00	24126.22	20009.22
2001	8640.00	-46900.00	1600.00	21962.293
2002	608.00	-5610.00	13991.70	18988.62
2003	597.00	4010.00	24235.06	19626.12
2004	943.00	5700.00	41338.04	34694.51
2005	-4210.00	1720.00	39982.83	42472.83
2006	-5500.00	-149.00	45448.42	51099.45
2007	-4030.00	-1200.00	51178.00	56409.00
2008	-4560.00	710.00	54637.30	58483.38
2009	-14300.00	-8810.00	42781.81	65857.81
2010	-12100.00	8390.00	31841.30	35510.30
2011	9070.00	-953.00	52634.37	44517.01
1991-2011	-30340.20	-47660.80	736913.50	799896.7

3.3. The Transportation Sector

The variations in the economic indicators for the transportation sector between 1991 and 2011 are depicted in Table 3. The sector witnessed an increase in EC in between years. However, about 38.09 % of the extra EC was due to intensity effect while 52.38 % was due to the structural effect. From 1996 to 2000 and 2005 to 2010, the sector witnessed a constant improvement stimulated by the I_{effect}. Similarly, the S_{effect} was responsible for the improvement in 1993, 1994, 1997, 1998, 2001, 2002, 2007 and 2011. Similarly, between 2005 and 2010, the trend EC > the real EC, a condition satisfactory for energy saving. The latter is ascribed to policy change, which comprise the reduction in the age of fairly used imported vehicles. Also, the declined in EC in the sector is associated to the botch in the railway structure, reduction in local air flights and car possession level.

Table 3: Changes in energy and structural effects on energy consumption in the Transportation Sector of Nigeria (1991-2011) (ktoe)

Year	I_{effect}	S_{effect}	Real Change	Trend
1991	-21.10	-54.69	1534.20	1609.953
1992	18.44	-272.00	1280.60	1571.037
1993	134.61	459.00	1816.72	1222.880
1994	234.41	1500.00	4217.43	2484.028
1995	103.00	1480.00	3317.63	4690.923
1996	178.00	-608.00	6686.03	7115.803
1997	-523.00	1180.00	9988.74	9334.476
1998	-646.00	3910.00	12168.29	8908.072
1999	-234.00	41.30	11318.11	11300.120
2000	-696.00	1100.00	3431.46	4539.409
2001	-495.00	4750.00	7333.29	3074.717
2002	-43.90	-703.00	2872.96	3619.272
2003	-349.00	77.00	3739.89	4011.693
2004	-529.00	1220.00	6012.93	5324.652
2005	183.00	-1400.00	5315.34	6170.710
2006	205.00	-476.00	6521.69	6792.304
2007	-351.00	-232.00	7509.44	8092.741
2008	-365.00	-1220	6983.57	8567.383
2009	-1190.00	653.00	7856.19	8388.322
2010	-828.00	-1930.00	3711.68	6468.524
2011	43.80	195.00	5733.25	5494.558
1991-2011	-5170.74	9669.61	119349.40	118781.60

3.4. The Overall Energy Rebound Effect

The total energy rebound effect (TRE) from 1991 to 2011 is presented in Fig. 4 for all the considered sectors. The overall economy within this period witnessed a reduction in EC of about 900000 ktoe. Moreover, the contributions of the indicators, I_{effect}, and S_{effect} to the overall economy was 37.26 % and 40.54 % respectively. The results also show that the rebound effect in agricultural (REA) and the rebound effect in transportation (RET) increased by 18.42 and 86.81 fold, respectively in 2011 compared to that in 1991while the rebound effect in the industrial sector decreased by 41 fold. Additionally, the contributions of the indicators between 1991 and 2011 to the overall economy were 7,568.46 ktoe for S_{effect}, and 34,676.20 ktoe for I_{effect}. A further breakdown of the rebound effect shows that technological upgrading is more in the transportation and agricultural sectors than the industrial sector. Since the industrial sector from the study was found to be the largest consumer of energy, technological improvements regarding production methods are necessary to reduce EC and increase efficiency.

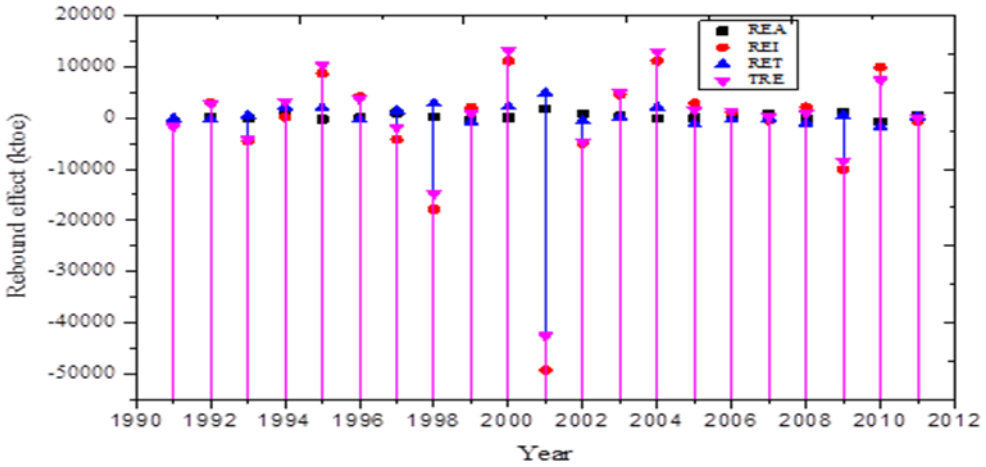

Fig. 4: Overall energy rebound effect (1991-2011)

4. Recommendations

Since economic progression stimulates energy consumption, ascertaining specific measures to cut down energy consumption in an economy is significant. Achieved by regulating the energy intensity and the structural dimension of the economy without compromising the economic activity. Adjustment arising from the industrial and product structure should be concomitant with planned adjustment of the economic structure. Technological change with high local content addressing issues of long-term progress planning of research and development should be a top precedence. This should include energy conversion methods and end-use applications that require high energy consumption. Adequate distribution of technical innovations that enhances energy efficiency should be encouraged by the government, through the provision of credit

facilities to production or manufacturing firms for upgrading.

5. Conclusion

The study presents the effect of the structural and intensity change indicators on three economic sectors of Nigeria (Agricultural, Industrial, and Transportation). For the transportation sector, the structural change was responsible for the surplus in EC during the study period. The two indicators I_{effect} and the S_{effect} has culminated the surplus in EC observed in the agricultural sector. Similarly, the EC in the industrial sector during the study period accounted for about 70 % of the overall EC and contributed principally to the economic progression. Therefore, energy efficiency measures are vital in this sector. The energy rebound effect shows that technological improvement is more in the transportation and agricultural sector than the industrial sector. For effective economic growth and sustainability, the economic indicators must be balanced through effective policy and technological upgrading.

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