Understanding industrial energy sources: A comparison between Electricity and Natural Gas using LMDI

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Abstract

This paper analysis the usage between electricity and natural gas in automobile manufacturing for the periods 2015-2018. Logarithmic Mean Divisia Index (LMDI) is employed to decompose the electricity and gas consumption data of company ABC (a large automobile manufacturer in South Africa). The main results reveal that company ABC for the period of study has made a shift in their energy consumption use, by increasing the use of gas as its source of energy which simultaneously saw a reduction in electricity usage, therefore reducing the amount of carbon emission emitted by company ABC.

Keywords:
LMDI, Natural gas. Electricity and energy.

1. Introduction

Industrial facilities around the world have been viewed as the major consumers of energy, about 37 percent of global energy usage is consumed by the industrial sector (Olanrewaju et al., 2012). In South Africa alone over 40 % of the country's energy is consumed by the industrial sector (Mahotas, 2010). Looking back into history this large consumption is mostly owed to the lack of awareness towards energy efficiencies and the low prices of energy (Inglesi-Lotz, 2012). Like other developing countries around the world South Africa now faces an energy crisis, hence sustainable manufacturing has become a vital subject.

In 2015 South Africa's energy supply was led by coal with 59% of the primary energy supply, followed by 20% owed to renewable resources and crude oil with 16%. Natural gas contributed 3% while nuclear contributed 2% to the total primary supply in 2015 as presented in Figure 1 (Keneilwe Ratshomo, 2018).

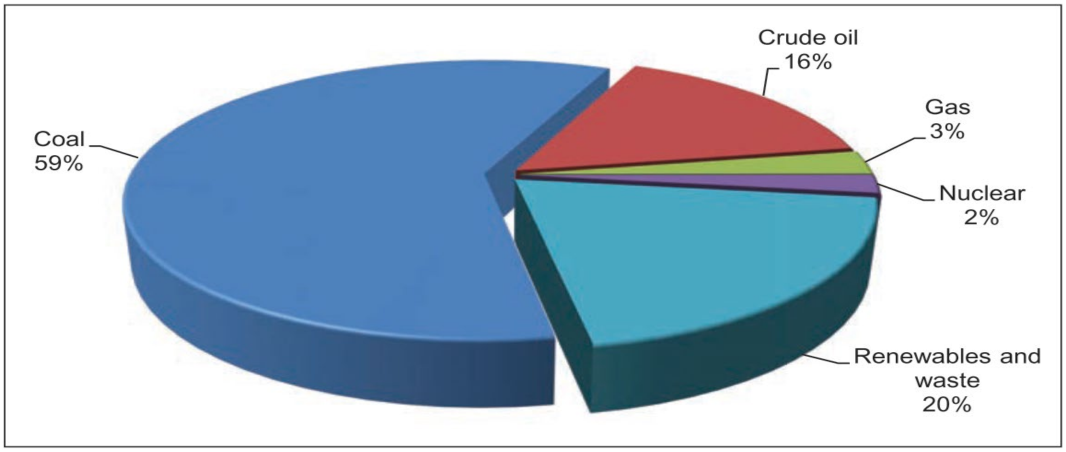

Figure 1: South Africa's energy supply mix (Keneilwe Ratshomo, 2018)

With energy being a fundamental resource for any kind of production activity, energy efficiency has been accepted as one of the most cost-effective approaches towards sustainable economic development and the reduction of the continuously increasing energy consumption in industries of both developed and emerging countries. Energy consumption in the industrial sector is influenced by three indicators, namely changes in activity, structure and intensity (Olanrewaju et al., 2012).

This paper seeks to compare the two common energy sources used in industry namely: Electricity (Produced by combustion of Coal) and Gas. Both are clustered as fossil fuels however they each have different environmental impacts with latter emitting (Anon, 2014). The paper seeks to argue that an increase in gas consumption contributes towards green energy and as a result, this represents positive energy efficiency, as there will be a shift from electricity to gas whereas an increase in electricity consumption contributes towards poor energy efficiencies.

This study will make use of a tool known as Index Decomposition Analysis (IDA). This paper is organized as follows: background of the study, followed by the literature review. A description of the logarithmic mean divisia index (LMDI). Details of the proposed method are discussed. These include use of the LMDI additive formulae. The case study comprises of one manufacturer known as Company ABC based on it having the highest output in the county. Results and discussion are presented as well as the conclusion.

2. Background of the study

As a popular tool used in energy studies IDA comprises of three contributions in its initial form namely they are: activity, structure and intensity (Bianco, 2020). The main objective of this tool is to decompose electricity consumption to the various impacts responsible for the consumption. Over the years the demand of using IDA in various application areas has grown which led to the adoption of the LMDI approach (Ang, 2015). As stated by Ang (2015) LMDI decomposition has two different methods namely being: LMDI-I and LMDI-II which can be differentiated by weights formulae used. Both these methods allow the use of additive and multiplicative decomposition. Ang (2015) further outlines the comparisons of eight LMDI models in their study giving researcher various options to choose from, to see these models please refer to Ang (2015). This paper will employ the additive decomposition technique. For other decomposition techniques as outlined by B. W. Ang (1996), please refer to Figure 2 below:

3. Literature review

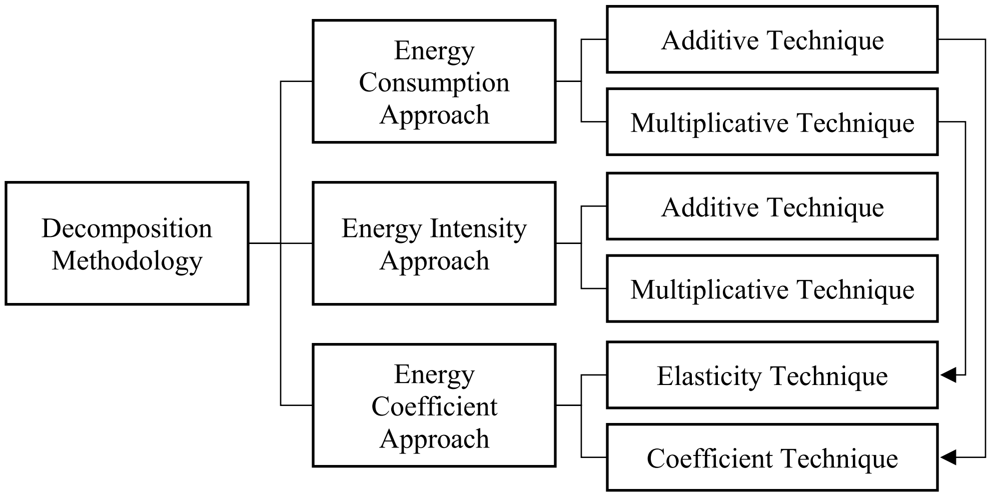

Figure 2: Three Different approaches to decomposing industrial energy consumption

(B. W. Ang, 1996)

IDA has been employed worldwide to study changes in energy consumption. Studies focus on changes at a national and sector level like Wenwen Wang (2014) who employed LMDI to analyze China's energy consumption, while Boonkham (2015) and Chontanawat et al. (2014) studied the changes of energy intensity of Thailand's' manufacturing industries, whereas Soni et al. (2017) studied the energy consumption of manufacturing sectors in India.

Research shows that employment of the LMDI method has increased over-time, which can be seen by B.W. Ang (2001) having applied a decomposition technique to achieve perfect in decomposition and consistency in aggregation. Ang et al. (1998) used decomposition to study the changes of energy and environmental indicators, Wood and Lenzen (2006) employed the LMDI to understand the Zero-value problems and Sun (1998) used a decomposition model to study changes in energy consumption and energy intensity. In addition to this, Shahiduzzaman and Alam (2013) employed the logarithmic mean Divisia approach to develop an empirical estimation of energy efficiency and other proximate factors that justified and detailed the energy intensity in Australia for the period 1978–2009 on a study that decomposed changes in energy intensity through means of fuel mix, structural changes and energy efficiency by utilizing sectoral and sub-sectoral levels of data.

Similarly Fernández González and Moreno (2015) employed a Divisia index-based method to study the factors behind changes in energy vulnerability of Spanish electricity generation and concluded that the increments in fuel prices contributed to a significant increase in Spanish vulnerability for the last two decades in a study which focused on the period 1998– 2011. Furthermore Kelvin Kan (2020) studied the use of energy in the South African manufacturing industry, this study applied IDA and the results indicated that for the period of interest there was a reduction in energy intensities which yielded an overall reduction in energy consumption in the manufacturing industry. Furthermore. it was outlined that manufacturers of chemical products, chemicals and refined petroleum products contributed 80% of the aggregate energy consumption.

Energy use in automobile industry

STAR (2015) conducted an energy study which involved 44 automobile assembly plants owned by 13 companies in 13 states. The study looked at the Energy Use Profile, Major Energy Uses, Distribution of Energy Performance and Greenhouse Gas Emissions. The study showed that electricity and natural gas were the common energy sources used in assembly plants. This study shows that coal has been largely phased out, however the use of fuels still accounts for 60 to 69 percent of the total energy use (*STAR*, 2015).

The study further outlines the biggest consumers of energy. In these plants process involving the use of heat such as paint booth curing ovens, hot water production and steam get energy from fuels, whereas Electricity is used in many various applications. Table 1 below lists the largest energy users in automobile assembly plants:

Table 1: Major energy users in automobile assembly plants (*STAR*, 2015)

Use/Process	Share of energy use
Paint Booths	30-50%
HVAC	11-20%
Lighting	15%
Compressed air	9-14%
Welding	9-10%
Material handling / tools	7-8%
Metal forming	2-9%
Miscellaneous / other	4-5%

The study further shows that the ratio of energy efficient plants is still low compared to those that are inefficient. Furthermore, it shows that manufacturers are more likely to focus on optimizing operations and or to introduce new technological upgrades. The study concludes by showing that electricity purchases are the largest source of carbon emissions, totaling around 4.4 million mtCO2e, with an estimated annual plant average of 83,000 mtCO2e.

This paper will take another step and focus on a sub-sector level by employing a single case study, which compares the consumption of electricity to the consumption of gas at Company ABC. The data used in this paper is in the form of a quantity indicator, which is known to measure the absolute level of energy consumption (Ang, 2015), and for these reasons as outlined by (Ang, 2015) it is best to use the additive decomposition analysis technique.

4. Methodology

A. Logarithmic Mean Divisia Index (LMDI) technique

LDMI was proposed by B.W. Ang (2001) after years of many studies of searching for a decomposition technique that does not live a residual term and has a consistent aggregate. LDMI was found to be perfect in decomposition and consistent in aggregation. As mentioned above, this technique is widely used to study the changes in energy consumption in various industries or economies (Ang, 2015).

Based on the study of Ang (2015), it can be deduced that the LMDI decomposition approach comprises two different methods, LMDI-I and LMDI-II. These methods differ in the weights formulae used and there are various studies where each of these models have been employed. A decomposition analysis problem can be formulated either additively or multiplicatively. In additive decomposition analysis, the arithmetic (or difference) change of an aggregate indicator such as total energy consumption is decomposed. However the aggregate change and decomposition results are given in a physical unit (Ang, 2015).

Changes in industrial energy consumption may be studied by quantifying the impacts of changes in three different factors: overall industrial activity (activity effect), activity mix (structure effect) and sectoral energy intensity (intensity effect). Below is Table 2 which outlines the LMDI formulae for decomposing changes in industrial energy consumption adopted from the study of (Ang, 2005).

Table 2: LMDI formulae for decomposing changes in industrial energy consumption (Ang, 2005)

IDA identity	$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i Q S_i I_i$	
Change scheme	Multiplicative decomposition $D_{tot} = E^T / E^0 = D_{act} D_{str} D_{int}$	Additive decomposition $\Delta E_{tot} = E^T - E^0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int}$
LMDI formulae	$D_{act} = \exp\left(\sum_i \frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)} \ln\left(\frac{Q^T}{Q^0}\right)\right)$ $D_{str} = \exp\left(\sum_i \frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)} \ln\left(\frac{S_i^T}{S_i^0}\right)\right)$ $D_{int} = \exp\left(\sum_i \frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)} \ln\left(\frac{I_i^T}{I_i^0}\right)\right)$	$\Delta E_{act} = \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln\left(\frac{Q^T}{Q^0}\right)$ $\Delta E_{str} = \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln\left(\frac{S_i^T}{S_i^0}\right)$ $\Delta E_{int} = \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln\left(\frac{I_i^T}{I_i^0}\right)$

This study employs LMDI-I Additive model adopted from the study of Ang (2005) as shown in the table above. To decompose the changes in energy consumption of manufacturer A, from period 0 to t, ΔE_{tot}, can be expressed as follows:

$$\Delta E_{tot} = E^T - E^0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \tag{1}$$

Additive Decomposition Formulae:

$$\Delta E_{act} = \sum_{ij} \frac{E_{ij}^T - E_{ij}^0}{\ln E_{ij}^T - \ln E_{ij}^0} \ln \frac{Q^T}{Q^0} \tag{2}$$

$$\Delta E_{str} = \sum_{ij} \frac{E_{ij}^T - E_{ij}^0}{\ln E_{ij}^T - \ln E_{ij}^0} \ln \frac{S_i^T}{S_i^0} \tag{3}$$

$$\Delta E_{int} = \sum_{ij} \frac{E_{ij}^T - E_{ij}^0}{\ln E_{ij}^T - \ln E_{ij}^0} \ln \frac{I_i^T}{I_i^0} \tag{4}$$

With each symbol defined below:

- ΔEact – Change in Activity
- ΔEstr – Change in Structural
- ΔEint – Change in Intensity
- ΔE - Change in energy consumption
- wi - Intensity effect
- Si - Structural effect
- Ii - Intensity effect
- ΔEij - Change in energy consumption at sub-sector (ij)
- Eij0 - Energy consumption at sub-sector (ij) for period 0
- EijT - Energy consumption at sub-sector (ij) for period T

5. Case study

Electrical and gas energy consumption data for periods 2015-2018 used in an automobile industry was collected. The data was arranged as follows: 2015 (Year 0) to 2016 (Year T), followed by 2016 (Year 0) to 2017 (Year T) and lastly 2017 (Year 0) to 2018 (Year T). Symbols used are "E" representing electrical energy and "C" representing gas energy, both are measure in gigajoules denoted as (GJ), data was collected from Company ABC. Table 4 below details the raw data: In the first column, the periods are shown; followed by electrical energy consumption data, followed by the gas energy consumption data and in the last column, the GDP output of Company ABC in units.

Table 6 and 7 outline the aggregate data for the period of study. Table 6 represents the electrical energy consumption data whereas Table 7 represents the gas consumption data. Both tables are structured as follows: column 1 is the period of study (Year 0) followed by the energy consumption, followed by the GDP output followed by the structure and intensity effect for year 0. This is followed by the period column for (Year T) followed by the energy consumption, followed by the GDP output followed by the structure and intensity effect for year T.

Table 4: Energy and output data of Company ABC

Year	E (GJ)	C (GJ)	Output (units)
FY2015	404062.2	305013.7	83146
FY2016	446571	410885.5	81228
FY2017	418869.2	383853.2	87919
FY2018	406163.5	402736.1	90684

Table 5: Electrical consumption Aggregate decomposition data of Company ABC

Year	E (GJ)	Output (units)	S0	I0	Year	E (GJ)	Output (units)	ST	IT
FY2015	404062.2	83146	0.33	4.86	FY2016	446571.02	81228	0.31	5.50
FY2016	446571	81228	0.32	5.50	FY2017	418869.23	87919	0.34	4.76
FY2017	418869.2	87919	0.35	4.76	FY2018	406163.47	90684	0.35	4.48
Total	1269502	252293	1	5.03		1271603.73	259831	1	4.89

Table 6: Gas consumption Aggregate decomposition data of Company ABC

Year	C (GJ)	Output (units)	S0	I0	Year	C (GJ)	Output (units)	ST	IT
FY2015	305013.68	83146	0.33	3.67	FY2016	410885.52	81228	0.31	5.06
FY2016	410885.52	81228	0.32	5.06	FY2017	383853.24	87919	0.34	4.37
FY2017	383853.24	87919	0.35	4.37	FY2018	402736.11	90684	0.35	4.44
Total	1099752.436	252293	1	4.36		1197474.862	259831	1	4.61

6. Results and discussion

Data decomposition results are presented in Tables 7 and 8. Table 7 presents decomposition results for the electrical energy consumption and Table 8 presents decomposition results for gas consumption of Company ABC. Column 1 of the table presents the periods, followed by the decomposition effects namely: Activity, Structure and intensity in that respective order.

From Table 7 it can be seen that Company ABCs electrical energy consumption increased by 2101.31 GJ for the period 2015 to 2018. The LMDI decomposition results show that between 2015 and 2016, the overall energy consumption increased by 42508.85 GJ, with the activity and intensity effect having a big contribution towards the increase and the structural effect contributing towards the reduction.

The LMDI decomposition results show that between 2016 and 2017 the overall energy consumption decreased by 27701.78 GJ, with the intensity effect contributing significantly towards the reduction and the activity and structural effect contributing towards the increase. Similarly, between 2017 and 2018 the LMDI decomposition results show that the overall energy consumption decreased by -12705.76 GJ, with the intensity effect contributing significantly towards the reduction and the activity and structural effect contributing towards the increase. This data is graphically presented in figure 5 below:

Table: 7 Electrical energy decomposition results of Company ABC

Year	ΔE_{tot}	ΔE_{act}	ΔE_{str}	ΔE_{int}
2015-2016	42508.85	12511.02	-22428.83	52426.66
2016-2017	-27701.78	12735.06	21505.60	-61942.44
2017-2018	-12705.76	12143.65	628.91	-25478.32
ΔE_{tot}	**2101.31**	**37389.73**	**-294.32**	**-34994.11**

Table: 8 GAS energy decomposition results of Company ABC

Year	ΔE_{tot}	ΔC_{act}	ΔC_{str}	ΔC_{int}
2015-2016	105871.84	10460.87	-18753.47	114164.43
2016-2017	-27032.27	11694.16	19747.84	-58474.28
2017-2018	18882.86	11576.49	599.54	6706.83
ΔE_{tot}	**97722.43**	**33731.53**	**1593.91**	**62396.99**

From Table 8 it can be seen that Company ABCs gas energy consumption increased by 97722.43 GJ for the period 2015 to 2018. The LMDI decomposition results show that between 2015 and 2016, the overall energy consumption increased by 42508.85 GJ, with the activity and intensity effect having a big contribution towards the increase and the structural effect contributing towards the reduction. Furthermore, the LMDI decomposition results show that between 2016 and 2017 the overall energy consumption decreased by 27032.27GJ, with the intensity effect contributing significantly towards the reduction and the activity and structural effect contributing towards the increase. Lastly, the LMDI decomposition results show that between 2017 and 2018 the overall energy consumption increased by 18882.86 GJ with all effects contributing towards this increase. This data is graphically presented in Figure 6 below:

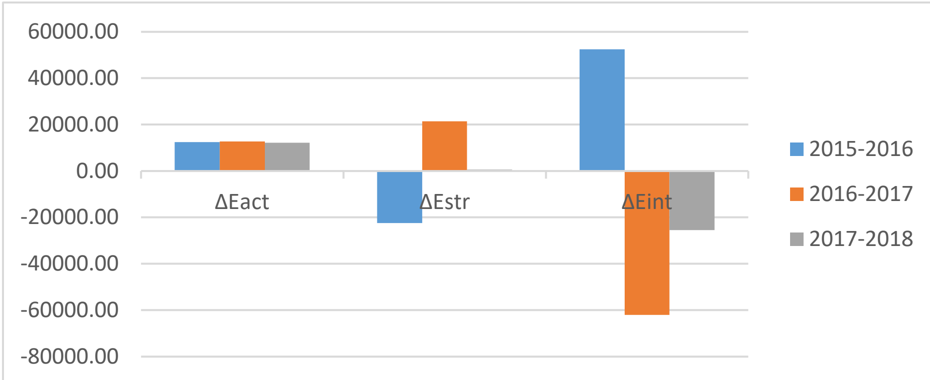

Figure 5: Electrical energy decomposition results

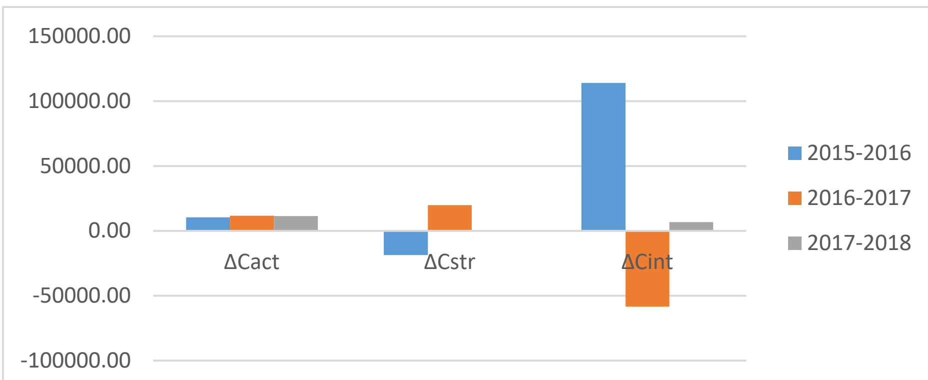

Figure 6: Gas energy decomposition results

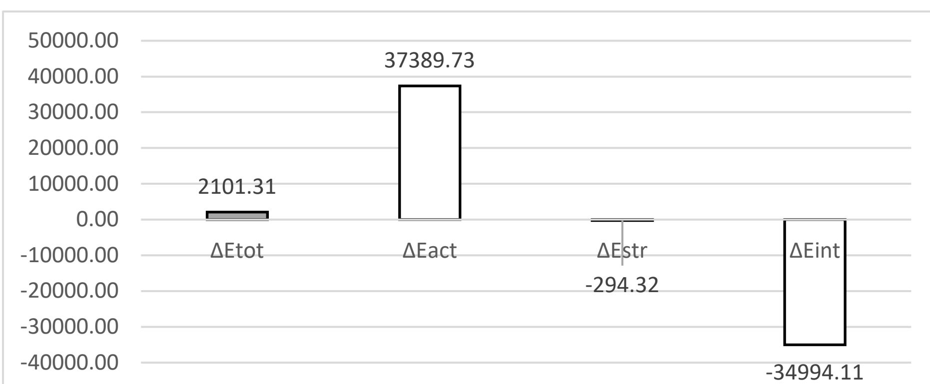

Figure 7: Summary of electrical energy decomposition results

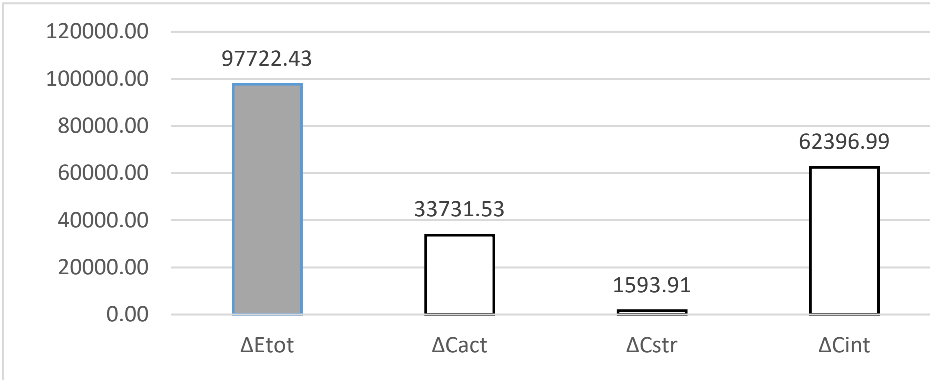

Figure 8: Summary of Gas energy decomposition results

Overall Figures 7 and 8 summarizes the total decomposition results for periods 2015 – 2018. From figure 7 it can be noted that although the overall electricity energy consumption increased, the increase was minor considering the outlook presented by the effects. The activity effect contributed significantly towards the increase, whereas the structural and the intensity effect made a significant contribution towards the reduction of energy consumption arising from the shift in the composition of industry output towards less energy-intensive sectors. From figure 8 it is noted that the total gas energy consumption increased significantly with all effects making a contribution. This increase is because of company ABC reducing its electrical energy consumption by using more gas.

7. Conclusion

In conclusion Anon (2014) stated that gas emits 50 to 60 percent less carbon dioxide (CO2) when combusted compared to coal or oil. Therefore, by Company ABC increasing the use of gas has a positive environmental outlook as compared to when electricity is used as the dominant energy source. This paper aims to show automobile industries one method of reducing their carbon emissions by using the resources they already have.

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