Analyzing Factors Responsible for Energy Use in the Construction Industry

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Abstract

This study emphasized on the famous factors (activity, structure and intensity) responsible for energy consumed in the South African Construction and Building industry between 1994 and 2016. A famous technique in the understanding of such factors was employed – Logarithmic Mean Divisia Index (LMDI). Structure effect was inconsequential on its impact on the change in energy consumption. Intensity on the other hand played its role to affecting the energy consumption positively but could not overturn the increase experienced during the period of study. Activity effect was the major contributor to the 88.7% increase in the energy consumed. Improvement on energy efficiency within this industry requires not just investment on new technologies but improvement on existing technologies will improve the various activities/operations needed within the industry.

Keywords
Construction and Building industry, LMDI, energy consumption, energy efficiency.

1. Introduction

Building and construction industry has been reported to be among the largest carbon emitters in the world (Wang *et al.*, 2018). 25% of the world's carbon emissions is contributed by building's energy use (Monahan and Powell, 2011). Apart from the contributions of building and construction industry as well as building's energy use to the global carbon emissions, the cement sector contributes additional 5% of the global carbon emissions (Worrell *et al.*, 2001). Year 2014 reported the cement industry consuming 7% of industrial energy consumption globally (Kermeli *et al.*, 2019). With the high level of process emissions during cement production, the industry is positioned second to the iron and steel industry in the emission category reporting 6% of global carbon dioxide emissions (International Energy Agency (IEA)., 2017). The management of carbon emissions has put increased pressure on the building and construction industry (Li *et al.*, 2017)(Wu, Xia and Wang, 2015). Cement production is associated to construction activity, in other words linked to building and construction and civil engineering and construction industries.

These emissions encountered by the building and construction are due to the industry's energy intensive nature (Wu *et al.*, 2019). To successfully manage the industry's carbon emission, analysis of previous trend of energy use becomes significant. This study focusses on evaluating the energy use from South Africa's construction between 1994 and 2016 by identifying those influencing factors, which can lead to effective policy making.

The increasing concern surrounding energy savings and emission reduction issues has led various studies to explore and quantify the factors responsible for those changes (Wang and Feng, 2018b). Such studies adopt decomposition techniques to understand such changes. The famous decomposition techniques are the structural decomposition analysis (SDA) and the index decomposition analysis (IDA). Both techniques are unique in their own way. The theory behind SDA was thoroughly reviewed by Rose and Casler (Rose and Casler, 1996). SDA's functionality is dependent on an input-output tables which limits its use as these tables are not readily available (Mi *et al.*, 2017). IDA's functionality on the other hand is dependent on the concept of index number (Hoekstra and Van den Bergh, 2003). Due to minimum data requirements, IDA is preferred by most researchers to SDA (Lin and Liu, 2015). From the revisions of various IDA methods, Ang (2004) concluded with Logarithmic Mean Divisia Index (LMDI) as the preferred choice given its simplicity when it comes to usage and interpretation of result as well as its theoretical foundation.

2. Literature

The application of LMDI to understand energy use is been witnessed in many studies. Some of these studies include identification of these factors responsible for the change of energy consumption in buildings at commercial sectors (Cai, Ren and Cao, 2014)(Zhou and Chen, 2015). From 1990 to 2009, Xu et al., (Xu *et al.*, 2012) analysed both energy consumption and CO2 emissions of China's cement industry by applying LMDI. The result spotted the increase of cement production to be responsible for the increase in energy consumption while decrease in clinker shares and structural shifts drove down both the consumption of energy and CO2 emissions.

Residential sector has also had its share of LMDI response when it comes to understanding the sectors energy use. One of those studies is that of Nie and Kemp (Nie and Kemp, 2014). Nie and Kemp (2014) investigated changes from appliances, change in floor space, population and energy mix contributions to the consumption of China's residential energy consumption from 2002 to 2010. With the application of LMDI, energy using appliances contributed most to the consumption of energy, next to floor while population was a stable factor and least important was the energy mix. Achão and Schaeffer (2009) looked at the Brazilian residential sector's energy consumption from 1980 – 2007. Electricity consumption was decomposed into the famous three factors which are the activity (consumers), intensity and structure effect (regional and income). Activity resulted in the most responsible factor for the consumption. Similar to the study of (Achão and Schaeffer, 2009) was the study of (Chung, Kam and Ip, 2011). Chung, Kam and Ip (2011) applied LMDI to Hong Kong's residential energy consumption from 1990 – 2007 to understand the contribution of households (activity), household type (structure) and energy consumption per household (intensity) and climate effect to the change in Hong Kong's residential energy consumption.

The transport industry has also made its mark when it comes to understanding those factors responsible for the industry's change in energy consumption. LMDI was applied to analyse the influencing factors of cargo transport's energy consumption in China from 2000 – 2002. Analyses revealed that GDP growth and degradation of transportation structures were responsible factors to the increase in energy consumption (Wu and Xu, 2014). At the Tunisian transport sector, factors responsible for the sector's change in fossil energy consumption through the use of LMDI between 1985 and 2014 was studied (Achour H, 2016). Transportation structure effect, transportation intensity effect, economic output and population scale effect all reported positively except energy intensity's effect on the consumption of energy, which reported negatively.

In trying to understand the Chilean industrial sector's energy consumption for the purpose of determining which of the country's sub-sectors had the greatest potential for energy consumption reduction, LMDI was applied. The study concluded with stable energy consumption throughout the period of study even though there was a rise in energy intensity (Duran, Aravena and Aguilar, 2015). Factors responsible for the variations in energy consumed at the Chinese's non-ferrous metal industry from 2000 to 2014 was explored (Wang and Feng, 2018a). The study's analysis was based on LMDI, resulting in labour productivity effect increasing the energy consumption and the main contributor to the energy increase next to industrial scale effect. Energy intensity effect on the other hand contributed strongly to the decrease in energy consumption.

Considering investment effect, energy intensity effect, economic structure effect, labour effect and energy mix effect from the study of (Wang *et al.*, 2014) through LMDI to understand these effects on China's energy consumption from 1991 to 2011; energy intensity effect was crucial in the reduction of energy consumption whereas investment effect was responsible for the increase in energy consumption. In defining the contributions of end-use energy structure, electricity generation efficiency, and fuel-mix in electricity generation related to the growth of CO2 emissions in Malaysia, Chong *et al.*, (2019) applied LMDI during 1978 – 1990, 1990 – 2002 and 2002 – 2014 periods. Results indicated energy intensity influencing changes in the energy-related CO2 emissions. In the decomposition of energy consumption to understand the factors responsible for aggregate energy consumption in EU-27, between 2001 – 2008, it was discovered that improved energy efficiency could not overturn Europe's economic activity pressure on the energy consumption. Most of the Mediterranean countries had an increase in energy consumption due to structural change.

Decomposing both China's energy consumption and energy intensity between 1995 and 2015 resulted in economic growth been the responsible factor on the energy consumption, while the reduction of energy consumption was due to energy intensity. The structural effect had little or no effect on the energy consumption. The western region of China consumed more energy than the eastern region especially between 2000 and 2015 period (Liu *et al.*, 2019). LMDI was applied to understand reasons behind the changes in Latvia's energy intensity from 2008 to 2012. The reduction of energy intensity after 2008 was as a result of the reduction on energy intensities within the sectors while an increase was due to expansion of energy demand sectors (Timma and Blumberga, 2014). Macao's energy-related emissions was decomposed using LMDI during 2000 to 2011 period. The factors reported to be responsible for the increase on energy-related emissions were the economic scale effect and energy structure effect (Chen *et al.*, 2018). In the analyses and decomposition of California's industrial energy intensity between 1997 and 2008 period, Hasanbeigi, De and Sathaye

(2012) applied LMDI. The result picked the intensity effect and structural effect as those factors responsible for the industry's energy reduction since 2000.

From literature, no study in the South African context in particular has holistically considered assessing the way energy was consumed on industries related to cement use. Similar studies in past only studied these sectors aggregated with other industrial sectors. It is imperative to have a clear understanding of those factors responsible for such increase in those sectors related to cement use. A direct effect of these changes will guide in policymaking. For such purpose of direct effect, IDA is most suitable for this task. The following section details the methodology and data, followed by the results and finally the conclusion.

3. Methodology and Data

With the assumption of aggregate U composed of m factors $(x_1, \dots, x_m)$, i.e. $U = \sum_i U_i$ and $U_i = x_{1,i}\, x_{2,i} \dots x_{m,i}$. A further assumption from period 0 to T leads to the aggregate changing from U^0 to U^T. The objective of the IDA (Additive LMDI for this study) is to understand the impacts of the m factors to the change in the aggregate.

3.1 Additive LMDI

Activity, structural and intensity effects are used in the analyses of the change in energy consumption during the periods concerned. The changes in energy consumed between the period 0 to the period T is decomposed thus: activity (the Q-term, which captures the sector's contribution to the complete gross domestic product (GDP)), energy intensity (the I-term, which refers to the energy efficiency changes), and the structural effect (the S-term, referred to as to shifts in the mix of products or activities). Each factor defines the changes in the amount of energy consumed within the periods concerned. The factors contributing to the changes are to be explained through the decomposition analysis with the terms below

E_i – Total energy consumed within sector i

E - Total energy consumed ($E = \sum_i E_i$)

Q_i - Production value within sector i

Q - Total value produced ($Q = \sum_i Q_i$)

S_i - Production share by sector i ($S_i = \frac{Q_i}{Q}$)

I_i - Energy intensity consumption within sector i ($I_i = \frac{E_i}{Q_i}$)

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i Q\, S_i I_i \quad (1)$$

$$E^T - E^0 = \Delta E_{tot} = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \quad (2)$$

With an assumption of an aggregate U composed of n factors $(x_1, \dots, x_n)$, thus, $U = \sum_i U_i$ and $U_i = x_{1,i}\, x_{2,i} \dots x_{n,i}$. Also assuming further from period 0 to period T culminating to an aggregate changes from U^0 to U^T. The objective of the additive LMDI will derive the contributions of the n factors to the change observed in the following form

$$\Delta U_{tot} = U^T - U^0 = \Delta U_{x1} + \Delta U_{x2} + \cdots + \Delta U_{xn} \quad (3)$$

$$\Delta E_{act} = \sum_{\mathrm{i}} \mathrm{w_i} \ln \left[\frac{\mathrm{Q^T}}{\mathrm{Q^0}}\right] \quad (4)$$

$$\Delta E_{str} = \sum_i w_i \ln \left[\frac{S_i^T}{S_i^0}\right] \quad (5)$$

$$\Delta E_{int} = \sum_i w_i \ln \left[\frac{I_i^T}{I_i^0}\right]; \quad (6)$$

$$\text{where } w_i = \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \quad (7)$$

3.2 Data

To understand those factors responsible for the changes in energy consumption within the sectors related to cement use in South Africa, energy and GDP data for 1994 and 2016 of building construction and civil engineering and other construction were analyzed. Figure 1 is a summary of the energy consumed and GDP for the subsectors under investigation. Quantec, a private company in South Africa provided the data. Production data, given in the form of GDP and energy are expressed in R million current prices.

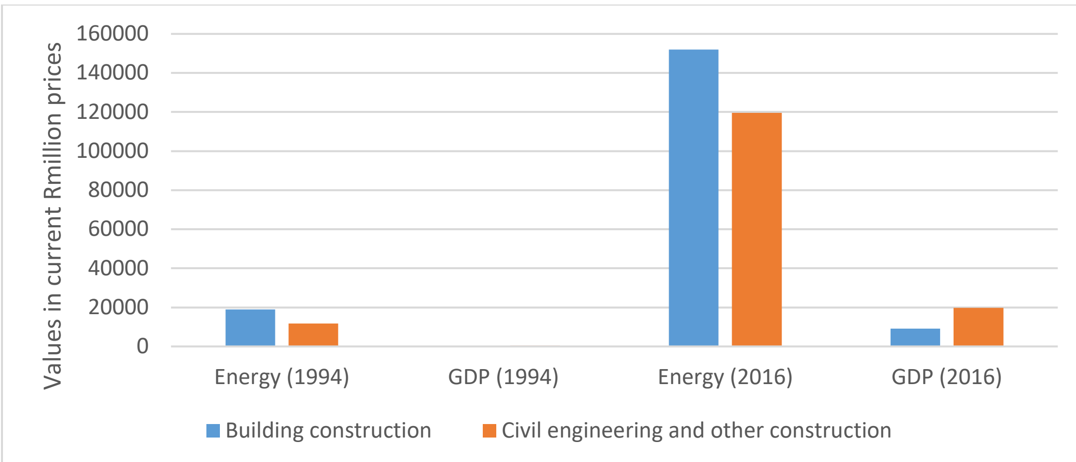

Figure 1: Data for GDP and Energy consumption for 1994 and 2016 for the observed industrial sectors in R million current prices

4. Results

The application of the additive LMDI gave an easy to understand result as depicted in Figure 2. Factors considered are the activity, structure and intensity. Assessing the contributions of these factors would inform if energy was consumed efficiently in the observed sectors. There was an increase in energy use by 88.7% from 1994 to 2016. Activity factor was the most responsible factor for the very high consumption of energy. Intensity on the other hand, though depicting an improvement in energy efficiency, could not overturn the role played by activity effect to increase the sectors energy consumption. A positive structure effect leans towards increased energy intensity. This study however, leans towards a reduced intensity, though minimal to have any effect in the reduction of energy consumption.

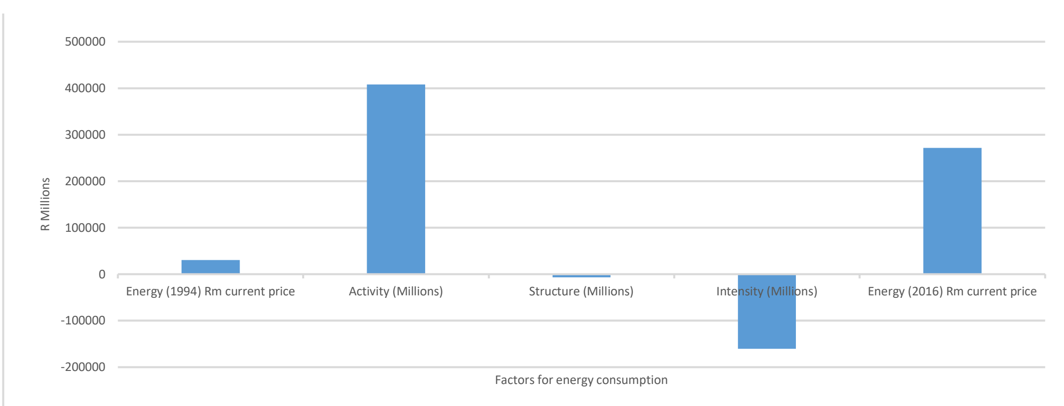

Figure 2. Result from the additive LMDI application

5. Conclusion

In this study, factors responsible for the increase in South Africa's energy consumption at the building construction and civil engineering and the construction industrial sectors was analysed between 1994 and 2016. These factors include activity, structure and intensity. Analysis was carried out using the additive LMDI. It can be concluded that (1) activity was the most responsible factor leading to 88.7% increase of energy from 1994 to 2016. Most of the activities involved in the industry are the extraction, processing and manufacture, transportation and assembly. Production of a concrete would require approximately 2.775 MJ of energy. The amount of energy is a lot especially with the number of concretes to be manufactured by these industries in the promotion of economic growth. (2) Intensity had a positive effect on the energy consumption through its reduction proving efficient use of energy though not sufficient enough to reduce the total consumption of energy. (3) Structure effect was unrecognizable in its impact made towards the increase of energy consumption during the period of study.

To improve on the energy efficiency as it concerns the various activities, not just investment on new technologies are important but an improvement of existing technologies would go a long way. This will lead to an improvement in the operational efficiency and optimization of the allocation of resources (in this case – energy) as it is required for the industry processes.

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References

Achão, C. and Schaeffer, R. (2009) 'Decomposition analysis of the variations in residential electricity consumption in Brazil for the 1980-2007 period: Measuring the activity, intensity and structure effects', Energy Policy, 37(12), pp. 5208–5220.

Achour H, B. M. (2016) 'Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the lmdi method.' Transport Pol, 52, pp. 64–71.

Ang, B. W. (2004) 'Decomposition analysis for policymaking in energy: Which is the preferred method?', Energy Policy. Elsevier BV, 32(9), pp. 1131–1139.

Cai, W. G., Ren, H. and Cao, S. P. (2014) 'Decomposition analysis of driving factors for building energy consumption in China.' Nat. Environ. Pollut. Technol., 13(1), p. 203.

Chen, B. et al. (2018) 'GHG emissions embodied in Macao's internal energy consumption and external trade : Driving forces via decomposition analysis', Renewable and Sustainable Energy Reviews, 82, pp. 4100–4106.

Chong, C. H. et al. (2019) 'The driving factors of energy-related CO2 emission growth in Malaysia: The LMDI decomposition method based on energy allocation analysis', Renewable and Sustainable Energy Reviews. Elsevier Ltd, 115(November 2018), p. 109356.

Chung, W., Kam, M. S. and Ip, C. Y. (2011) 'A study of residential energy use in Hong Kong by decomposition analysis, 1990-2007', Applied Energy, 88(12), pp. 5180–5187.

Duran, E., Aravena, C. and Aguilar, R. (2015) 'Analysis and decomposition of energy consumption in the Chilean industry', Energy Policy. Elsevier, 86, pp. 552–561.

Hasanbeigi, A., De, S. and Sathaye, J. (2012) 'Analysis and decomposition of the energy intensity of California industries', Energy Policy. Elsevier, 46, pp. 234–245.

Hoekstra, R. and Van den Bergh, J. C. (2003) 'Comparing structural decomposition analysis and index.' Energy Econ., 25(1), pp. 39–64.

International Energy Agency (IEA). (2017) Energy technology perspectives 2017 – Catalysing Energy Technology Transformations. Paris, France.

Kermeli, K. et al. (2019) 'The scope for better industry representation in long-term energy models: Modeling the cement industry', Applied Energy. Elsevier, 240(March 2018), pp. 964–985.

Li, X. et al. (2017) 'Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach', Automation in Construction, 84(September), pp. 195–206.

Lin, B. and Liu, H. (2015) 'CO2 emissions of China's commercial and residential buildings: evidence and reduction policy.' Build. Environ., 92, pp. 418–431.

Liu, H. et al. (2019) 'Analysis of regional difference decomposition of changes in energy consumption in China during 1995 - 2015', Energy. Elsevier Ltd, 171, pp. 1139–1149.

Mi, Z. et al. (2017) 'Pattern changes in determinants of Chinese emissions.' Environ. Res. Lett., 12(7), p. 074003.
Monahan, J. and Powell, J. C. (2011) 'An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework', Energy and Buildings. Elsevier B.V., 43(1), pp. 179–188.
Nie, H. and Kemp, R. (2014) 'Index decomposition analysis of residential energy consumption in China: 2002-2010', Applied Energy. Elsevier Ltd, 121, pp. 10–19.
Rose, A. and Casler, S. (1996) 'Input-output structural decomposition analysis: a critical appraisal.', Econ. Syst. Res., 8(1), pp. 33–62.
Timma, L. and Blumberga, D. (2014) 'Index decomposition analysis for energy sectors in Latvia', Energy Procedia. Elsevier B.V., 61, pp. 2180–2183.
Wang, M. and Feng, C. (2018a) 'Decomposing the change in energy consumption in China's nonferrous metal industry: An empirical analysis based on the LMDI method', Renewable and Sustainable Energy Reviews. Elsevier Ltd, 82(October 2017), pp. 2652–2663.
Wang, M. and Feng, C. (2018b) 'Exploring the driving forces of energy-related CO2 emissions in China's construction industry by utilizing production-theoretical decomposition analysis', Journal of Cleaner Production. Elsevier Ltd, 202, pp. 710–719.
Wang, T. et al. (2018) 'Estimating the environmental costs and benefits of demolition waste using life cycle assessment and willingness-to-pay: A case study in Shenzhen', Journal of Cleaner Production. Elsevier Ltd, 172, pp. 14–26.
Wang, W. et al. (2014) 'Using a new generalized LMDI (logarithmic mean Divisia index) method to analyze China's energy consumption', Energy. Elsevier Ltd, 67, pp. 617–622. doi: 10.1016/j.energy.2013.12.064.
Worrell, E. et al. (2001) 'Carbon dioxide emissions from the global cement industry.', Annual Reviews Energy Environ, 26, pp. 303–329.
Wu, H.-M. and Xu, W. (2014) 'Cargo Transport Energy Consumption Factors Analysis: Based on LMDI Decomposition Technique', IERI Procedia, 9(2012), pp. 168–175.
Wu, P. et al. (2019) 'Analyzing the influence factors of the carbon emissions from China's building and construction industry from 2000 to 2015', Journal of Cleaner Production. Elsevier Ltd, 221(2019), pp. 552–566.
Wu, P., Xia, B. and Wang, X. (2015) 'The contribution of ISO 14067 to the evolution of global greenhouse gas standards - A review', Renewable and Sustainable Energy Reviews. Elsevier, 47, pp. 142–150.
Xu, J. et al. (2012) 'Energy consumption and CO 2 emissions in China's cement industry : A perspective from LMDI decomposition analyses, Energy Policy. Elsevier, 50, pp. 821–832.
Zhou, L. and Chen, W. Y. (2015) 'Status and decomposition analysis on building energy consumption of China in the last decade.' J. Renew. Sustain. Energy, 7(6), p. 063134.

Biography

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