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Macro, meso, and micro decomposition of energy consumption in Ghana: Role of shocks (local and global) and energy policy interventions

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ABSTRACT

This study conducted a macro, meso, and micro index decomposition analysis of energy consumption in Ghana from 2013 to 2020, highlighting the roles of local (e.g., power crisis) and global (e.g., COVID-19) shocks, as well as energy policy initiatives on technical efficiency improvement. We found that technical efficiency improvements varied at different times of the implementation period of energy policy initiatives and across various macro, meso, and micro-sectors of the economy. Technical efficiency improvement varied significantly across these sectors but worsened much more in service sector during periods of local and global shocks. Additionally, the importance of activity, structural, and intensity effects differed over time and across the macro, meso, and micro-sectors of the economy. We discuss the policy implications of these findings.

1. Introduction

As climate change continues to strongly influence global economies, mitigation and adaptation efforts are now high on national and global agendas. The overwhelming ratification of the Paris Agreement and Nationally Determined Contributions by countries testifies to the global and national commitment to addressing climate change concerns. Given the critical role of energy consumption in atmospheric greenhouse gas emissions [1], governments worldwide are encouraged to intensify their efforts by (1) reducing the share of fossil fuel energy sources in the total energy mix [2] and (2) optimizing energy use [1] through effective energy transition and demand-side management policies.

Several energy policies have been implemented to address these challenges. According to IEA statistics,[1] there are 227 policies aimed at improving renewable energy and 109 policies focused on energy efficiency in Africa. In Ghana, a sub-Saharan African country with high biomass dependence, reflecting the energy structure in much of Africa, notable policies include the Net Metering Code of 2015, the Ghana National Energy Policy of 2010, the L1 1932 Energy Efficiency of 2008 (i.e. regulation that bars the importation and manufacture of incandescent lamps, refrigerators and fridge, etc.), and the Energy Efficiency Standards and Labelling Regulations of 2005, all of which are currently in force.

Despite these efforts, Ghana continues to experience an increase in energy consumption from high-carbon energy sources compared to low-carbon ones, thereby increasing the country's ecological footprint. Carbon dioxide emissions (metric tonnes per capita) in Ghana rose from 0.4 metric tonnes per capita in 2010 to 0.6 metric tonnes per capita in 2020, which is 1.5 times higher than the 2010 level [3]. Achieving an energy system that aligns with environmental sustainability goals will require effective demand-side management interventions in the energy sector.

Meaningful management of future energy consumption patterns requires a concurrent understanding of the underlying factors (i.e., techno-economic and structural) and the effectiveness of existing policies. This will provide valuable insights for current policies and assist in the formulation, design, and implementation of new policies. The objective of this study is to use the index decomposition analysis (IDA) technique to understand the underlying factors influencing energy consumption patterns in Ghana across major economic sectors (i.e.,

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[1] https://www.iea.org/policies?region%5B0%5D=Africa&topic%5B0%5D=Renewable%20Energy&topic%5B1%5D=Energy%20Efficiency

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industry, service, and agriculture) and their sub-sectors, particularly highlighting the key roles played by COVID-19, the power crisis, and other energy policies from 2013 to 2020. We analyze energy consumption across various sectors: the macro sectors (industry, service, and agriculture), the meso sectors within services (hotels and restaurants, education, transport and storage, and health and social work) and industry (mining and quarrying, manufacturing, and construction), and the micro sectors within manufacturing (food products and beverages, basic metals, fabricated metal products, wood and wood products, paper and paper products, chemicals and chemical products, textiles, rubber and plastics, and others). The selection of these meso and micro sectors is primarily based on data availability and their significant contribution to the total final energy consumption of their respective macroeconomic sectors.

Since its introduction in the 1970s, IDA methods have been widely used by researchers [4], international organizations, and government institutions to assess demand patterns or the effectiveness of existing policies (UNFCC, 2005; [5–7]). For example, the IEA [8] applied IDA to assess the effectiveness of energy efficiency policies on global energy use. The IPCC [9] used IDA to analyze the techno-socioeconomic drivers of global carbon emissions, while Keramidas et al. [10] assessed how COVID-19 and the 2 °C target impact energy systems and emissions. In a recent review, Wang and Yang [4] reported that as of the end of March 2023, more than 10,000 studies had applied the decomposition method for various reasons. Apart from its strong appeal to policymakers, IDA is simple, easy to interpret, and highly flexible.

There are several studies on the decomposition of energy consumption at both the aggregate and sectoral levels (see Ref. [4], for a review of the literature). However, the balance of evidence is biased towards economy-wide studies rather than sectoral studies. Wang and Yang [4] revealed that, for the period considered, economy-wide studies dominated sector-focused studies, except in 2016. Interestingly, most of these sector-level studies originated from countries with robust data systems, such as those in Europe ([11–13], among others), Asia ([13–17], among others), and America ([7,13], among others). Even in such studies, the focus is largely on the macro sectors, with limited analysis of the subsectors within these macro sectors.

In Africa, obtaining the high-level disaggregate data required for such studies is challenging due to poor data systems. Consequently, meso- and micro-level analyses of energy consumption are rare. Nonetheless, there are some quasi-attempts in the literature. Tenaw [18] conducted an economy-wide decomposition of energy intensity in Ethiopia. Oteng-Abayie et al. [19] decomposed energy intensity for macro sectors (i.e., industry, service, and agriculture) in Ghana, while Akrofi et al. [20] decomposed energy consumption for macro sectors such as commerce and services, industry, agriculture and fishery, and residential and transport in Ghana. Additionally, Inglesi-Lotz and Blignaut [21] and Oludolupo [22] decomposed energy consumption for the subsectors of the industrial sector in South Africa. These Africa-based studies not only rarely consider meso- and micro-level analyses but also do not simultaneously account for the roles of global and local shocks and energy efficiency policies. This is particularly crucial for developing crisis response strategies and for the monitoring and evaluation of government demand-side management interventions.

This study contributes to the scant literature in Africa. First, we analyzed energy consumption patterns and their underlying factors (i.e., activity, scale, and intensity effects) in the macro sectors of the economy: industry, service, and agriculture. Second, for the industry and service macro sectors, we examined the energy consumption patterns and underlying drivers for the meso sectors. Third, we examined the drivers of energy consumption patterns for the micro sectors within the manufacturing meso sector. Understanding the energy consumption patterns at the meso and micro levels provides detailed information for energy policy formulators and designers in the country. Sectors are unique in response to shocks and underlying energy consumption patterns. Therefore, by applying the decomposition to high-level disaggregate data, we address possible macro, meso, and micro sector heterogeneities. This is critical for developing an energy policy that reflects the sector's needs and behavior and can guarantee the desired changes.

Additionally, based on the observed patterns and changes, we assessed the potential role of some energy policies and local (power crisis) and global (COVID-19) shocks [10] in explaining technical efficiency improvement in energy consumption. This section addresses concerns about policy efficacy and how the demand side of the energy sector responds to or has been influenced by adverse shocks. As adverse shocks introduce uncertainty in public policy, they push policymakers to consider how to make their energy policies more resilient to shocks. The practical utility of this study extends beyond Ghana, given the similarities in energy consumption structures and localized shocks, such as power crises, as well as the common exposure to global shocks in the sub-region.

The rest of the study is organized as follows: Section 2 provides a context description; Section 3 describes the data and methodology; Section 4 discusses the findings of the study; and Section 5 concludes with policy recommendations.

2. Review of energy policies implemented during the period under review

In Ghana, the Energy Commission (EC) is responsible for technical regulation and advises the Ministry of Energy on energy planning, policy development, and implementation. Over the years, the Commission has developed and implemented several energy efficiency and renewable energy policies and strategies. The following paragraphs outline some of these initiatives.

The use of high-energy-consuming and inefficient appliances for illumination, food preparation, and cooling is a significant cause of energy loss in the economy. In 2012, the Commission actively engaged in raising awareness about energy consumption and conservation to maintain a sustainable energy supply. This involved educating consumers through print and radio media and stakeholder engagements about the need for and techniques of conserving energy resources. Additionally, the Commission collaborated with the private sector to expand its *Efficient Refrigerating Appliance Rebate Program*, encouraging the use of energy-efficient refrigerating equipment. This initiative aimed to replace inefficient appliances through a combination of energy performance standards, labeling consumer incentives, and regulatory oversight of the importation of inefficient electrical appliances. The program's primary goal was to help consumers purchase new and energy-efficient refrigerators by providing rebates. By the end of 2012, over a thousand used refrigerators had been handed in by consumers, with an equivalent number of new and efficient refrigerators acquired [23]. The total amount of power saved from the program was approximately 400 GWh, nearly 40 % of the Bui Hydroelectric Power Plant's yearly production. Rebate recipients saved an average of 385 kWh per year compared to the global annual average refrigerator consumption of 600 kWh [24]. To reduce energy consumption in public buildings, the Commission installed *automatic power factor correction capacitors* at select facilities [23].

In the same year, the government introduced the *National Energy Efficiency and Conservation Promotion Strategy Document (NEECPS)*, outlining plans to adopt energy efficiency measures and initiatives for the mid-term (2012–2015). The goal was to ensure at least a 10 % reduction in all types of energy usage in Ghana. In response to the United Nations Secretary General's Sustainable Energy for All (SE4ALL) campaign, the Commission also developed the *Ghana Sustainable Energy for All Country Action Plan*. This plan aimed to ensure universal access to modern and clean energy services, increase the proportion of renewable energy in the global energy mix, and significantly improve energy efficiency by 2030. SE4ALL focuses on the productive use of energy in agriculture (irrigation), agro-processing, and fisheries, and advocates for LPG usage, upgraded cookstoves, and biogas use in health facilities, boarding schools, and prisons [23]. In 2013, the first National Woodstoves Festival showcased various improved wood fuel cookstoves created by local artisans, promoting their use throughout Ghana. Baseline research was initiated to investigate awareness levels of improved cookstoves [25].

Also in 2013, the Energy Commission issued 22 provisional licenses for a total solar PV production capacity of 2055 MW. The Commission developed a *Net Metering Code and a Renewable Energy Grid Code* to promote renewable energy and created a framework for establishing renewable energy funds [25]. The 2008 law restricting the importation of old refrigeration equipment came into force in July 2013, ensuring that only appliances meeting minimum energy efficiency criteria were imported. Standards and labeling for household refrigerators, air conditioners, and compact fluorescent lamps were established, along with a ban on importing used refrigerating appliances and air conditioners [25].

In 2016, the power industry faced challenges such as inadequate power supply infrastructure, overreliance on hydropower, insufficient gas supplies, and high fuel costs for electricity generation. *The National Rooftop Solar Photovoltaic (PV) Program* (RSP) was established in February 2016 to reduce grid demand by deploying 200,000 rooftop solar PV systems in residential and commercial buildings. The program's medium-term goal was to deliver 200 MW of peak load reduction in the national grid using solar PV technology. Beneficiaries received a capital subsidy in the form of free solar panels with a maximum capacity of 500 W peak, provided they had the Balance of System (BOS) components installed [24].

In line with the Renewable Energy Act 2011 (Act 832), the Commission launched the first Ghana Renewable Energy Fair (Conference and Exhibition) in February 2015, which has since been held annually to provide a platform for renewable energy industry experts to discuss sustainable growth approaches [24]. By the end of 2016, approximately 5700 Certified Electrical Wiring Professionals (CEWPs) and Certified Electrical Wiring Inspectors (CEWIs) had graduated. This training and examination program, which started in February 2013, aimed to ensure safe wiring practices and the use of quality energy-efficient materials in electrical works, thereby reducing energy consumption [26].

3. Data and method

3.1. Data type and sources

To identify the factors influencing energy consumption in Ghana and measure their contributions, we analyzed energy consumption and GDP data from the industrial, service, and agricultural sectors from 2013 to 2020 using data from Ghana Statistical Service (GSS) and Energy Commission (EC), Ghana. Specifically, the study examines the impact of structural, activity, and intensity effects on energy use in macro, meso, and micro sectors in Ghana.

The decomposition analysis for macro, meso, and micro sectors used the sector's share of GDP at 2013 constant prices (in million Ghana cedis) and their associated final energy usage (measured in ktoe), utilizing the output approach to quantify GDP.

For the macroeconomic sectors, which encompass the entire industry, service, and agriculture sectors, the decomposition of energy consumption reflects the entirety of these sectors and not overall economic-wide energy consumption. However, for the meso and micro sectors, concerns over matched productivity and energy consumption data led us to focus on selected meso service and industry sectors and micro manufacturing sectors.

An initial review of the data revealed several inconsistencies, particularly in the documentation of energy use. For example, there were no energy consumption figures available for water production (a meso industrial sector) from 2000 to 2020. Similar issues were identified for the meso service and manufacturing micro sectors.

Of particular interest is the residential sector, a significant contributor to energy consumption in Ghana, which we did not include in this study, despite the availability of energy consumption data. This study used a value-added based output measure, which is only available for commercial sectors. Additionally, identifying a common activity indicator for the residential sector is complex due to the wide range of appliance applications with varying efficiency levels across households. Table 1 lists the sectors and subsectors used in the decomposition analysis.

Data for macro and meso sectors covered the period from 2013 to 2020, while the analysis for manufacturing micro subsectors was limited to 2014–2020 due to the availability of disaggregated GDP data only for this period.[2]

Lastly, the details of various energy policies implemented by the government, as outlined in Ghana's Annual Energy Reports, literature, and discussions with officials from the Energy Commission, were instrumental in explaining some of the trends and changes observed over the years.

3.2. Index decomposition analysis (IDA) method

This study employed the Index Decomposition Analysis (IDA) method, widely recognized in energy decomposition literature [27]. The two primary approaches within the IDA method are the Divisia and Laspeyres indices. The Divisia approach is favored due to its benefits of perfect decomposition, which satisfies the factor-reversal test and leaves no residual term in the outcome. It also meets the time-reversal test, ensuring that results are independent of the base year. Additionally, this approach is consistent in terms of aggregation [28]. It handles datasets with zero or negative values effectively and is straightforward in both usage and interpretation due to its uncomplicated decomposition formula. Furthermore, the connections between the multiplicative and additive versions are easily demonstrable. Conversely, the Laspeyres technique effectively addresses zero-value situations and is easily comprehensible; however, its decomposed outcomes often include a significant proportion of residual terms [29].

This study uses the Divisia decomposition technique, which can be classified as either multiplicative or additive. The multiplicative method decomposes the ratio of change relative to the base year while the additive method breaks down the difference in consumption between two time periods [28]. Both approaches provide valuable insights into the factors affecting energy consumption.

However, according to Ang [30], additive Divisia factor decomposition may take precedence over multiplicative Divisia factor decomposition in specific instances, although the reverse may also be true. The choice of technique should be based on its utility in understanding the data and identifying sectors for future initiatives, such as energy conservation efforts. As recommended in specialized literature [28,30–32], this study employs the additive Divisia decomposition technique to examine the factors influencing variations in energy consumption in Ghana's economic sectors from 2013 to 2020.

The additive Divisia decomposition technique considers three elements to determine variations in energy consumption: sectoral energy intensity (intensity effect [IE]), activity mix (structure effect [SE]), and economic activity (activity effect [AE]). Below, we illustrate the decomposition of energy consumption. Equation (1) defines energy intensity as the ratio of energy consumption (E) to output (Q), which can be reformulated as Equation (2).

$$EI = E/Q \tag{1}$$

$$E = Q^{*}EI \tag{2}$$

[2] Details of the output and energy consumption data utilized in this study are available in the supplementary file.

Table 1
List of sectors included.

Macrosector	Meso sectors	Manufacturing micro sectors
A. Industry	1. Mining and Quarrying 2. Manufacturing 3. Construction	1 Food products and beverages 2 Textiles 3 Wood and wood products 4 Paper and Paper Products 5 Chemicals and chemical products, Pharmaceuticals, medicinal chemicals, and botanical products 6 Rubber and plastic products 7 Basic metals 8 Fabricated metal products, except machinery and equipment Others[a]
B. Service	1. Hotels and Restaurants 2. Education 3. Health and Social Work 4. Transportation and storage	NA
C. Agricultural	NA	NA

[a] Consists of cement manufacturing, leather and related products, printing, coke and refined petroleum products, nonmetallic mineral products, computer, electronic and optical products, electrical equipment, furniture, machinery and equipment, motor vehicles, trailers and semi-trailers, other transport equipment, and repair and installation of machinery and equipment.

Summing over energy consumption by units (i), total energy consumption can be expressed as Equation (3). We then multiply energy intensity ($\sum_i \left(\frac{E_i}{Q}\right)$) by Q_i/Q_i, where Q_i represents the output share of unit 'i'. This is expressed in Equation (4). Next, we rearrange to obtain Equation (5), where EI_i denotes the energy intensity of unit 'i' and S_i denotes unit i's share of output (Q_i)) in total output (Q).

$$E = Q^* \sum_i \left(\frac{E_i}{Q}\right) \tag{3}$$

$$E = Q^* \sum_i \left(\frac{E_i}{Q}\right) * \left(\frac{Q_i}{Q_i}\right) \tag{4}$$

$$E = Q^* \sum_i \left(\frac{E_i}{Q_i}\right) * \left(\frac{Q_i}{Q}\right) = Q^* \sum_i EI_i{}^* S_i \tag{5}$$

Based on the framework in Equation (5), the activity effect (AE), intensity effect (IE), and structural effect (SE) are derived as Equations (6)–(8), respectively.[3]

$$AE = (Q^t - Q^o)^* \sum EI_i^o{}^* S_i^o \tag{6}$$

$$IE = Q^0 * \sum \left(EI_i^t - EI_i^0\right)^* S_i^o \tag{7}$$

$$SE = (Q^o)^* \sum \left(S_i^t - S_i^o\right)^* EI_i^o \tag{8}$$

Where,

Q^o = Gross Domestic Product (GDP) in the baseline year, i.e. 2013;

Q^t = GDP in the final year, i.e. 2020;

EI_i^0 = Energy intensity in the baseline year, i.e. 2013;

S_i^o = Sectors share of GDP in the baseline year, i.e. 2013.

EI_i^t = Energy intensity in year 2020;

S_i^t = Sector's share of GDP in year 2020;

Equation (8) then provides the additive Divisia breakdown of changes in total energy use:

$$\Delta E_{tot} = E^T - E^O = AE_t + IE_t + SE_t \tag{8}$$

Here, ΔE_{tot} represents the total change in final energy consumption from period T to 0. Thus, the activity effect (AE_t)), structural effect (SE_t)), and intensity effect (IE_t) are each separately decomposed from the overall change in energy consumption (ΔE_{tot}).[4]

The activity effect (AE) pertains to fluctuations in primary energy consumption resulting from changes in gross value added or gross domestic product (GDP), or the scale of overall energy end-use activities. It captures the influence of production scale or activities on energy consumption, with positive values indicating increased energy consumption due to scale expansion.

The intensity effect (IE) delineates variations in total final consumption per unit resulting from changes in intensity. It accounts for the impacts of energy-use technologies, with negative values indicating reduced energy consumption due to enhanced technical efficiency resulting from technological advancements.

The structural effect (SE) encompasses variations in final energy consumption due to shifts in economic structures, reflecting changes in the relative weight of each economic sector or sub-sector compared to the total economic activity. It elucidates the composition of energy end-use activities. Notably, many industrialized nations, such as the United Kingdom, have transitioned away from energy-intensive sectors towards service-related activities, leading to decreased energy usage. Negative values signify a reduction in energy consumption attributed to the transition towards less energy-intensive activities. We observe the trends in these identified effects over time and assess the potential roles of demand-side management policies, and local and external shocks in explaining the patterns.

4. Results and discussion

This section presents the findings of the study. Firstly, we analyze the determinants of energy consumption across macroeconomic sectors from 2013 to 2020, considering both chain and period-long variations. Secondly, we investigate the factors influencing energy usage within the service and industrial meso sectors, culminating in an examination of the decomposition of energy consumption within the manufacturing

[3] The practical implementation of Equations (6) to (9) for the various sectors and subsectors is detailed in the supplementary document.

[4] The residual component (RC), serving as an indicator of model fit, is calculated by subtracting the total predicted change in energy consumption (i.e., the sum of AE, IE, and SE) from the actual change in energy consumption. Smaller values suggest a better fit of the model. For details on computing both the total change (TC) and residual components (RC), please refer to the supplementary file.

micro sector. Throughout our analysis, we scrutinize these factors during policy adjustments and external and local shocks, such as the power crisis and the COVID-19 pandemic. Details regarding the primary data utilized and the methodologies employed for decomposition are provided in the supplementary file.

4.1. Decomposition of energy consumption by macro sectors

This section decomposes final energy consumption for the major economic sectors: industry, service, and agricultural sectors. The discussion and presentation of the results proceed as follows: first, we discuss the decomposition of final energy consumption for industry, followed by service, and agricultural sectors.

Fig. 1 illustrates the decomposition of final energy consumption in the industrial sector. Between 2013 and 2020, the activity effect primarily drove final energy consumption in the macro industry, followed by the intensity and structural effects, corroborating the findings of Oludolapo [22]. The positive contributions of activity and structural effects outweighed the negative intensity effect, resulting in an overall increase in final energy consumption in the sector.

However, a period-by-period analysis reveals varying patterns depending on the yearly changes. For instance, although the activity effect consistently contributed positively throughout the period, its impact diminished and was lower compared to the intensity effect, particularly during the power crisis and COVID-19 periods. The activity effect's contribution was notably lower at the peak of the power crisis (2014/2015), with a gradual recovery in 2015/2016, peaking in 2016/2017. These patterns suggest that the scale of output at the height of the power crisis was significantly lower, accounting for the reduction in energy consumption. Subsequent recovery in output, which translated to rise in consumption, discounts the possible spillover effects of the power crisis in other years. Similarly, the reduced positive contribution of the activity effect was much significant during the COVID-19 period than the economic crisis period of 2017/2018.

The structural effect was negative from 2013 to 2015, became positive in 2015/2016, peaking in 2016/2017, and then fell marginally in 2017/2018, turning negative through 2018–2020. These dynamics suggest significant shift in production mix from more energy intensive to less energy intensive products, particularly during the period of the pandemic.

The intensity effect was negative except during 2014/2015 and 2019/2020, when the country experienced a protracted power crisis and the COVID-19 pandemic. This indicates that technical efficiency in energy consumption worsened, particularly during the COVID-19 pandemic and the power crisis periods. These shocks likely negatively impacted investment decisions in energy-efficient technologies, as such negative shocks introduce uncertainty that discourages investment. Periods of technical efficiency improvement in the industrial sector – indicated by negative intensity effects - can be attributed to autonomous efficiency improvements (estimated at 1 % per year) and the implementation of government demand-side management policies and interventions. Notable demand-side management policies during these periods included energy efficiency and labelling standards, as well as the National Energy Efficiency and Conservation Strategy (NEECS).

Similar to the macro-industrial sector, the period-long analysis indicates that the activity effect accounts for a significant proportion of total final energy consumption in the service sector, followed by the structural effect and then the intensity effect (see Fig. 2). Despite the negative structural effect, the combined positive contributions of the activity and intensity effects drove final energy consumption in the service sector upwards from 2013 to 2020.

A period-wise decomposition highlights the significance of both local and external shocks in explaining energy consumption in the service sector. The activity effect remains consistently positive, though its magnitude varies across different periods. During the power crisis (2014/2015), the positive activity effect diminished, recovered marginally in 2015/2016, peaked in 2016/2017, declined in 2017/2018, increased in 2018/2019, and drastically fell in 2019/2020. These fluctuations underscore that both the roles of local and external shocks in influencing the scale of activities in the macro service sector, with external shocks playing the most significant role. The varying positive and negative structural effects reflect the changing energy consumption patterns within the sector during this period.

The intensity effect was positive during crisis periods and negative during the implementation of demand-side management policies. The positive intensity effect suggests that the power crisis and COVID-19 might have hindered efficiency improvements in final energy consumption in the service sector. Conversely, improvements in technical efficiency were observed during periods of demand-side management policy implementation, such as the National Energy Efficiency and Conservation Promotion Strategy (2012–2015).

The dynamics in the agricultural sector show similar trends (see Fig. 3). A period-long analysis reveals that final energy consumption in the agricultural sector is primarily driven by the activity effect, followed by the structural and intensity effects. The combined positive contributions of the activity and intensity effects outweighed the negative

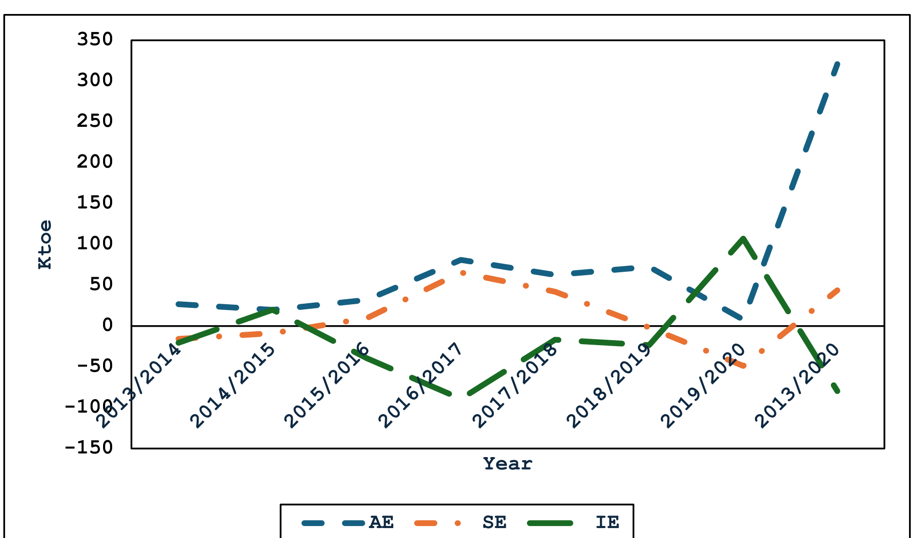

Fig. 1. Additive chain linked and period long decomposition for industrial Sector.

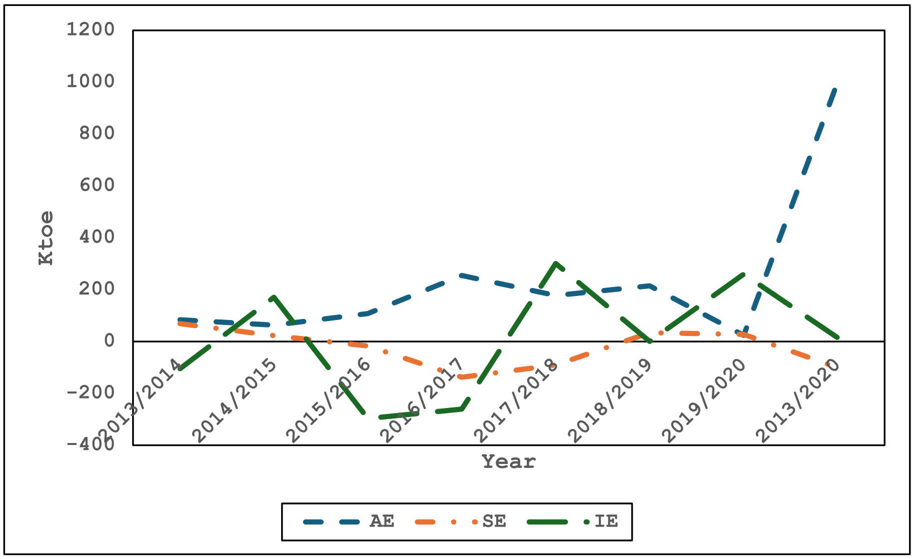

Fig. 2. Additive chain linked and period long decomposition for service Sector.

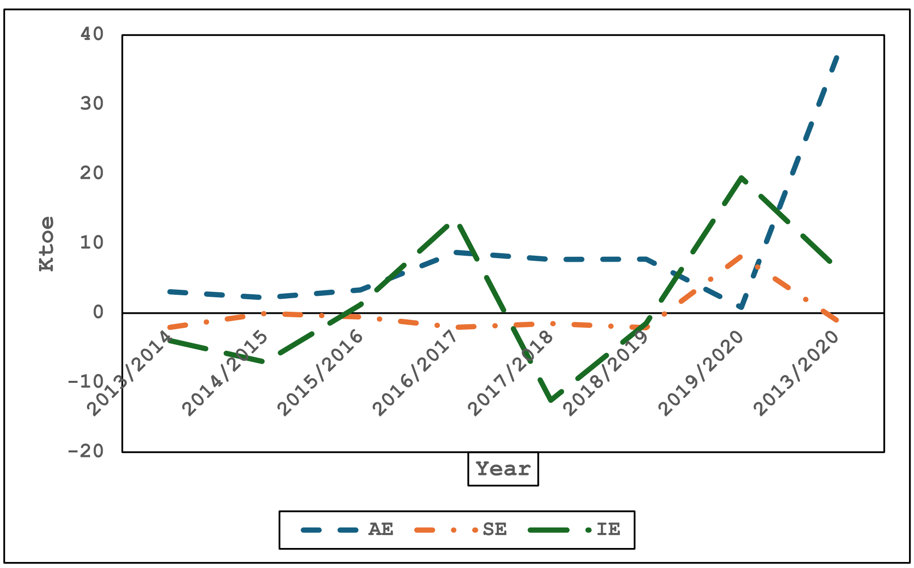

Fig. 3. Additive chain linked and period long decomposition for agriculture Sector.

structural effect, leading to an overall increase in final energy consumption in the macro agricultural sector.

The period-by-period decomposition indicates that, despite a consistently positive activity effect, it declined in 2014/2015, recovered in 2015/2016, peaked from 2016 to 2019, and then fell significantly in 2019/2020. This suggests that both the power crisis and COVID-19 might have influenced the scale of activities in the macro agricultural sector, leading to a decline in energy consumption.

The intensity effect was positive in 2016/2017 and 2019/2020, indicating a decline in technical efficiency improvement during those periods. However, the intensity effect was negative in 2013/2014, 2014/2015, and 2017/2018, suggesting that technical efficiency improvement during those years did not worsen. The structural effect was largely negative, except during the power crisis and COVID-19 periods.

The macro-sector decomposition reveals various factors contributing to the increase in final energy consumption. In the industrial sector, the rise was driven by the combined positive effects of the activity and structural factors, which outweighed the negative intensity effect. In the service and agricultural sectors, the increases were due to the combined positive activity and intensity effects, despite the negative structural effect. These dynamics underscore the heterogeneous nature of the factors driving final energy consumption across different economic sectors during the reviewed period. This highlights the necessity for tailored demand-side management policies for each sector.

All sectors demonstrated technical inefficiency and scale challenges during periods of domestic and external shocks, with the degree of challenge being higher during the periods of external shocks. Specifically, during the COVID-19 pandemic and the power crisis periods, scale of production and technical efficiency declined. The latter suggests rising technical inefficiency in energy consumption across sectors, with the service sector suffering the most during these periods. The COVID-19 crisis severely impacted Ghana's economy in 2020, affecting sectors differently [33]. Findings from the Ghana Statistical Service's (GSS) COVID-19 Business Tracker Survey, conducted in partnership with the World Bank and the United Nations Development Programme (UNDP), revealed that the demand and supply shock of the COVID-19 outbreak significantly impacted Ghanaian enterprises. This led several firms to close or reduce output, resulting in the loss of approximately 42,000 jobs during the partial lockdown and a reduction of about 700,000 working hours [34].

Globally, progress in energy efficiency improvement slowed before COVID-19 and worsened during the pandemic (Akorli and Adom, 2023 [35]; & IEA, 2020 [36], IEA, 2021 [37]). The pandemic delayed investment in energy-efficient technologies by businesses and households, reduced government support for energy efficiency programs, and introduced additional uncertainty to energy efficiency efforts.

Additionally, the challenging global financial environment during 2017/2018 significantly impacted energy investments, affecting both the demand and supply of energy. On the demand side, businesses and households reduced their spending on energy-using appliances, which negatively influenced energy efficiency. The tight credit conditions made investments in energy-saving technologies less appealing. For example, the manufacturing sector notably decreased its investment in research and development as well as in energy-efficient technologies. On the supply side, new investments in refineries and oil and gas wells declined sharply.

Ghana experienced its most intense and protracted power crisis during 2014/2015, which significantly affected major sectors of the economy [38]. The power crisis reduced GDP growth to 4.2 %, down from 7.1 % in 2013 and 8.8 % in 2012. According to the Institute of Statistics, Social and Economic Research [39], the country lost approximately US$55.8 million per month and nearly US$680 million in 2014, representing 2 % of GDP, due to the power crisis.

Technical efficiency improvements seem to have benefited from demand-side management policies implemented between 2012 and 2016, particularly in the industry and service sectors. These policies included the Refrigeration Appliance Rebate Program, incandescent bulb replacement, energy performance standards and labeling, consumer incentives, regulatory oversight, a ban on importing inefficient/high energy-consuming used electrical appliances, and increased public energy efficiency sensitization programs. This may indicate the narrow focus of government demand-side management policies, which predominantly target high energy-consuming sectors.

4.2. Decomposition of energy consumption by meso and micro sectors

The preceding section analyzed the decomposition of final energy consumption across macroeconomic sectors. While this analysis highlights the heterogeneous nature of these major sectors in terms of the factors driving consumption and their potential susceptibility to local and external shocks, it does not account for the within-sector heterogeneity. Meso and micro sectors vary in their resistance or vulnerability to shocks and in their energy consumption dynamics. However, decomposing energy consumption at the meso and micro sector levels requires extensive data.

In this section, we decompose final energy consumption for meso and micro sectors within the macro sectors from 2013 to 2020, where reliable matched energy and productivity data are available. Therefore, the total effects presented may not fully represent the overall sectoral position. Specifically, we examined meso and micro sectors within the industrial sector and meso sectors within the service sector of the economy.

4.2.1. Industry meso sectors

The industrial meso subsectors include wood production, construction, water and sewage, electricity, mining and quarrying, and manufacturing. However, due to data availability constraints, we present a decomposition for three meso sectors of the industrial economy in Ghana: mining and quarrying, construction, and manufacturing. Notably, the mining and quarrying and manufacturing sectors account for more than 90 % of the total final energy consumption in the industrial sector. In 2019, these two meso sectors contributed approximately 98 % of the total final energy consumption in the industrial sector.

Figs. 4 and 5 illustrate the decomposition of final energy consumption for the mining and quarrying, manufacturing, and construction subsectors, respectively. In the mining and quarrying subsector, long-term analysis reveals that the increase in energy consumption is primarily attributed to positive activity and structural effects, which outweigh the negative intensity effect (see Fig. 4). However, the annual decomposition does not display a consistent pattern regarding the contribution of the three identified effects. The activity effect is consistently positive but lower during periods of power and economic crises, turning negative during the pandemic.Fig 6

The structural effect is negative during crisis periods, indicating that these shocks may have impacted the output mix in the sector. The intensity effect is predominantly negative except during the power crisis and COVID-19 period, suggesting that these shocks may have adversely affected energy efficiency investments in the mining and quarrying sector. Periods of negative intensity effect coincided with the implementation of demand-side management policies. Furthermore, improvements in energy efficiency can be attributed to adherence to international environmental and energy standards governing mining operations.

For the manufacturing sector, long-term analysis shows that positive activity and intensity effects outweighed the negative structural effect, leading to an overall increase in final energy consumption. Period-by-period analysis, however, reveals varying dynamics regarding the weight of each identified effect. Activity effects are generally positive but decrease during power and economic crises, becoming negative during the pandemic, indicating that these shocks may have affected the scale of activities in the manufacturing sector.

The intensity effect was positive during 2013/2014, 2017/2018, and 2019/2020, indicating that technical efficiency in the manufacturing sector deteriorated during the economic crisis and the pandemic. Periods of negative intensity effect align with the implementation of demand-side management policies, suggesting that such interventions may have improved technical efficiency in the manufacturing sector. The structural effect has generally been negative, except during the power crisis and COVID-19 periods.

In the construction sector, long-term analysis shows that the positive activity effect outweighed the combined negative structural and intensity effects, leading to an increase in energy consumption. The year-by-year decomposition indicates that the intensity effect was the primary driver of energy consumption in the construction sector. Except for 2015/2016 (NEECPS implementation year), when the intensity effect was negative, the sector experienced general technical inefficiency, which intensified in 2016/2017 and 2018/2019.

From the industry meso-sector analysis, significant heterogeneities are observed. First, the underlying reasons for energy consumption patterns during the review period varied by subsector. Second, scale of activity and technical efficiency declined most during the COVID-19 pandemic, which was not uniform across the subsectors but felt more in the manufacturing subsector. Also, the scale of activity in the manufacturing subsector suffered negatively during the power and economic crisis periods. For the mining and quarrying subsector, the scale of activities and technical efficiency suffered negatively during the power crisis period, but only the scale of activity suffered during the economic crisis period. These heterogeneities underscore the importance of recognizing the unique characteristics of these sectors and the need for tailored interventions. Also, they underscore the varying important roles that local and external shocks played in explaining energy consumption patterns in the industry meso sectors.

4.2.2. Decomposition of final energy consumption by manufacturing microsectors

The manufacturing subsector seem to have suffered more in terms of technical efficiency and scale effects during periods of both external and local shocks. However, given the diversity within the manufacturing subsector, it would be unreasonable to conclude that all subsectors

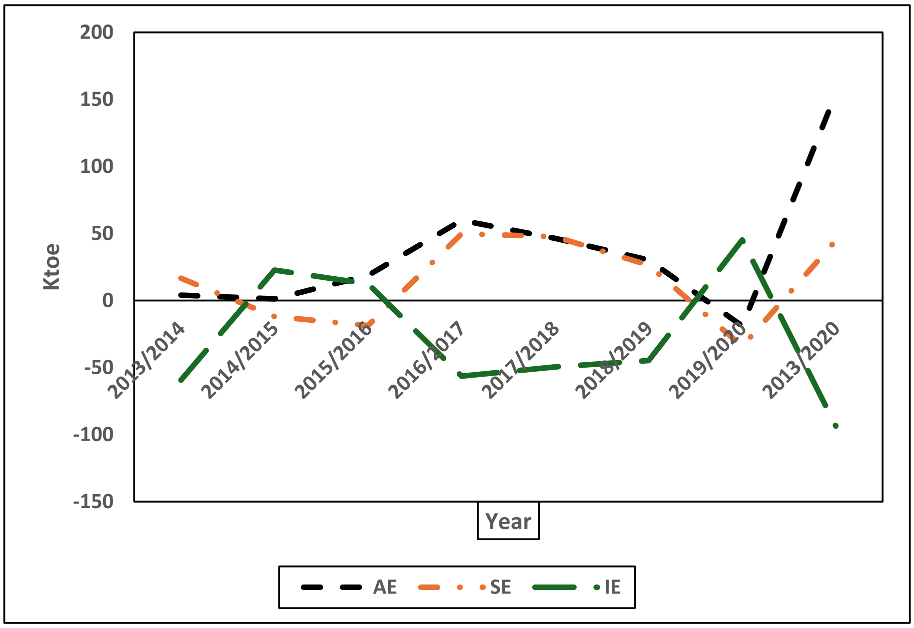

Fig. 4. Additive chain linked and period long decomposition for mining and quarrying.

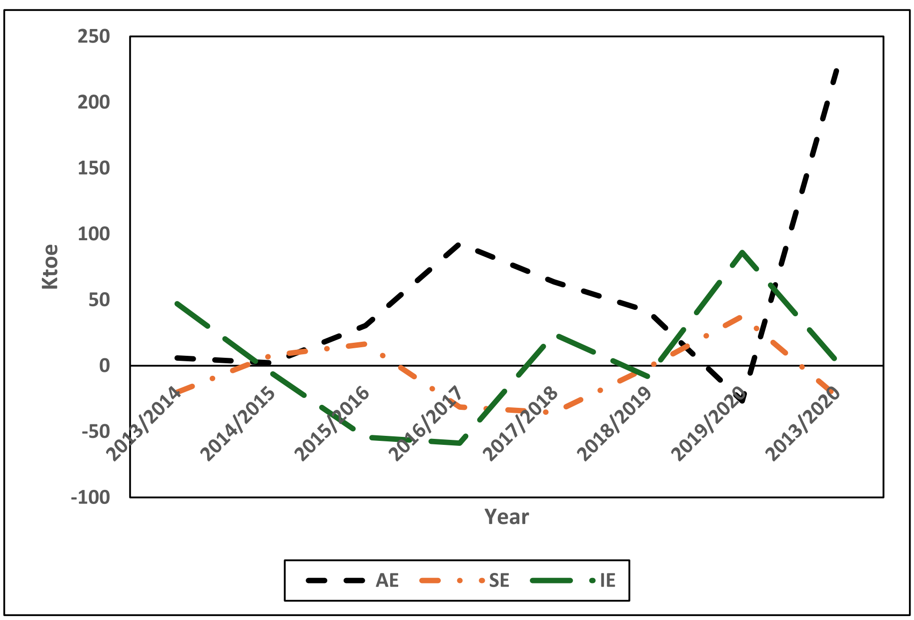

Fig. 5. Additive Chain Linked and Period Long Decomposition for Manufacturing sector.

experienced the same fate. In this section, we decompose energy consumption for the manufacturing micro sectors from 2014 to 2020. Due to data availability, we included only those subsectors for which both energy consumption and productivity data were available.[5]

Given the numerous subsectors within the manufacturing sector, we restrict the decomposition analysis to three specific periods: the long-term view (2014–2020), the power crisis (2014–2015), and the pandemic period (2019–2020). This approach keeps the information concise and directly relevant to the thesis of the article, avoiding an overload of textual tables. Table 2 presents the results.

Regarding the period-long decomposition (see last column of Table 2), for the food products and beverages subsector, the combined positive activity and intensity effects outweighed the negative structural effect, resulting in an increase in final energy consumption between 2014 and 2020. A similar pattern was observed in the textiles, paper and paper products, and basic metals subsectors, suggesting that the growth in the scale of activities, coupled with a decline in technical efficiency, contributed to the rise in energy consumption. This occurred despite these sectors experiencing significant negative structural effects.

In the food products and beverages subsector, the negative structural effect could be attributed to the closure of major beverage-producing companies such as the Coca-Cola Bottling plant in Kumasi in 2015 and an increase in the importation of canned and bottled drinks. In the textiles subsector, this effect can be linked to the shutdown of once-thriving textile companies like Printex in 2016 and other related industries in Ghana, due to the influx of cheaper foreign clothes.

[5] Disaggregate analysis for the service and agricultural sectors was not performed due to similar data availability concerns for the micro sectors.

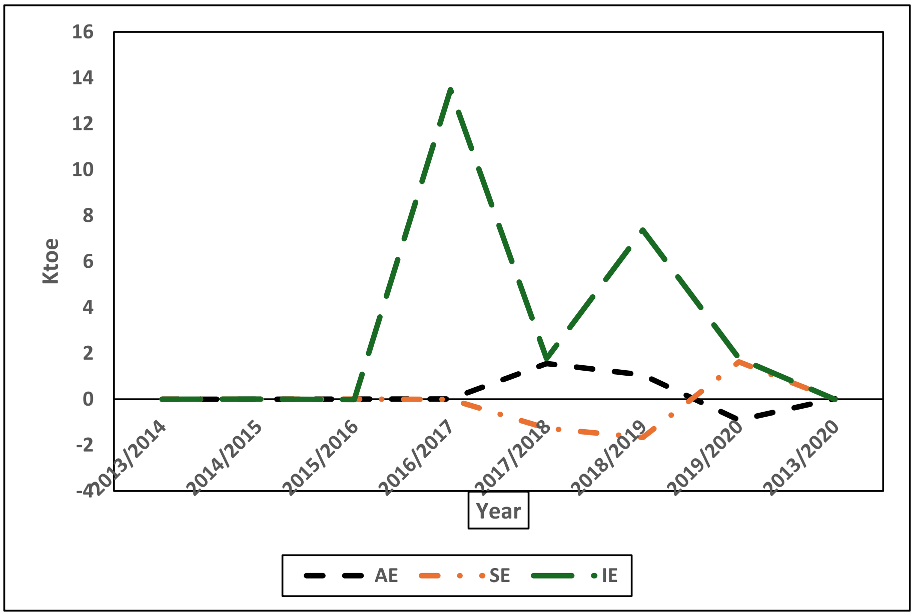

Fig. 6. Additive Chain Linked and Period Long Decomposition for Construction sector.

For the wood and wood products, chemicals, and other sectors, the combined positive activity and structural effects outweighed the negative intensity effect, leading to an increase in energy consumption during the period under review. This suggests that technical efficiency improved in these sectors, possibly due to autonomous advancements or government demand-side management policies. However, these improvements were insufficient to offset the positive activity and structural effects. In the rubber and plastic sector, the combined activity effect outweighed the negative structural and intensity effects.

In the fabricated metal products subsector, the increase in energy consumption was due to positive activity, structural, and intensity effects, indicating a deterioration in technical efficiency during the period under review.

The first and second columns of the table highlight the decomposed effects during the COVID-19 and power crisis periods. Given that these shocks tend to disincentivize investment in energy-efficient technologies, our discussion focuses on their implications for energy efficiency. Except for the paper and paper products subsector and other manufacturing subsectors, which demonstrated resilience to technical efficiency improvements during the power crisis, most sectors were vulnerable. The food and beverage subsector was particularly affected during the power crisis period.

During the COVID-19 pandemic, sectors such as textiles, wood and wood products, paper and paper products, rubber and plastics, and food and beverages were vulnerable, as they experienced significant decline in technical efficiency, with the situation being worse in the food and beverage subsector. Conversely, the other manufacturing subsectors showed resilience during the pandemic. Overall, both shocks (i.e., local and external) seem to have played a significant role in deteriorating energy efficiency in the food and beverage and other manufacturing subsectors.

The above analysis highlights significant heterogeneities in the factors influencing consumption patterns and the role that power crisis and COVID-19 may have played in the deteriorating state of technical efficiency in energy consumption in some micro sectors of the manufacturing subsector. Different subsectors exhibited varying reasons for changing consumption patterns, indicating that multiple mechanisms were at play. Similarly, technical efficiency improvement varied across subsectors; some sectors demonstrated resilience, while others showed strong vulnerability during periods of crisis.

These evolving dynamics in understanding energy demand consumption patterns underscore the need to prioritize sector- or firm-specific considerations when planning and designing national energy demand policies.

4.2.3. *Service meso sectors*

Similarly, due to data availability constraints, we considered the following meso sectors within the macro service sector: hotels and restaurants, transport and storage, education, and health and social work. These sectors contribute a significant share of the final energy consumption in the sector. In 2013 and 2019, these sectors contributed 95 % and 93 %, respectively, to total final energy consumption in the service sector.

Figs. 7 and 8 present the decomposition of final energy consumption for the selected service meso sectors. For the hotels and restaurants subsector, long-term analysis reveals that a significant positive intensity effect, complemented by a positive activity effect, outweighed the negative structural effect, resulting in increased final energy consumption between 2013 and 2020. The year-by-year decomposition shows varying patterns in the significance of these identified effects. The activity effect was largely positive but lower during both the power and economic crises, turning negative during the pandemic, indicating that the scale of activities suffered more during the pandemic. The structural effect was largely positive until the economic crisis and the pandemic. Except for 2016/2017, the intensity effect remained largely positive, peaking during the pandemic. Thus, all three shocks affected the scale of activities and technical efficiency in the hotels and restaurants subsector suffered during period of local and external shock, with the effect being felt more during the pandemic. However, there is no evidence to suggest that the subsector's technical efficiency improved during periods of government demand-side management interventions.Fig 9 and 10

In the transport and storage subsector, long-term analysis shows that a significant positive activity effect, complemented by a positive structural effect, outweighed the negative intensity effect, leading to an increase in overall energy consumption (see Fig. 8). Given the energy-intensive nature of the transport sector [40], increasing energy consumption has serious environmental implications. According to the 2020 International Energy Agency Report [35], the transport sector is a major contributor to global greenhouse gas emissions. The effect dynamics change in the year-to-year decomposition. The activity effect diminished during crisis periods, especially during the pandemic when it became negative, indicating that the pandemic might have exerted

Table 2
Decomposition of final energy consumption in the manufacturing microsectors.

Manufacturing Sub-Sectors	Power crisis period					COVID period					Period Long View (2014–2020				
	AE	SE	IE	TC	RC	AE	SE	IE	TC	RC	AE	SE	IE	TC	RC
Food products and beverages	3.995	−3.926	13.666	13.734	0.069	4.033	−21.10	56.00	38.93	3.64	85.87	−38.74	56.086	103.216	6.554
Textiles	0.065	−0.256	2.644	2.454	0.142	0.080	−0.902	0.384	−0.438	0.068	1.407	−2.44	7.14	6.110	4.615
Wood and wood products	0.098	0.586	0.604	1.288	−0.085	0.113	−2.730	1.607	−1.010	0.562	2.103	5.380	−3.16	4.320	3.346
Paper and Paper Products	0.043	0.205	−0.040	0.207	0.001	0.077	−1.994	2.854	0.937	1.027	0.918	−0.297	2.078	2.698	−0.321
Chemical and chemical products, Pharmaceuticals, and medicinal chemical and botanical products	0.069	0.495	0.059	0.623	−0.017	0.086	−0.667	−0.399	−0.980	1.027	1.478	0.835	−0.784	1.529	0.209
Rubber and plastic products	0.063	0.041	0.996	1.101	−0.030	0.074	−0.221	−1.182	−1.329	−0.030	1.362	−0.064	−0.649	0.649	0.252
Basic metals	0.035	−0.260	0.551	0.326	0.068	0.067	0.216	−1.348	−1.065	0.077	0.751	−0.083	0.779	1.447	−0.217
Fabricated metal products, excl machinery, and equipment	0.048	−0.314	0.877	0.611	0.092	0.083	−0.429	−1.77	−2.116	−0.098	1.032	0.011	0.127	1.169	−0.052
Other Manufacturing sectors	5.977	−8.316	−10.08	−12.422	0.072	4.619	84.48	−17.03	72.07	3.453	128.491	25.788	−71.223	83.055	24.436

greater influence on the scale of activities in the subsector than other shocks.

The structural effect oscillated between positive and negative contributions, indicating a changing production mix in the subsector with implications for energy use patterns. The intensity effect was positive during the crisis periods, suggesting that these shocks may have hindered technical efficiency improvements in the transport and storage sector. Nonetheless, there is evidence that periods of technical efficiency improvement coincided with significant government demand-side management interventions. Legislation was passed during this period to discourage the importation of over-aged cars, increasing the importation of more energy-efficient and low fuel-consuming vehicles, along with the advent of ride-hailing services such as Uber, Bolt, Tango, and Taxify. This was complemented by the introduction of the luxury vehicle tax from July 2018 to July 2019, taxing fuel-guzzling vehicles with engine capacities of 33.00 cc and above, and imposing hefty penalties on the importation of overaged, high-fuel-consuming vehicles.

For the education subsector, long-term analysis shows that energy consumption increased due to positive intensity (i.e., inefficiency), structural, and activity effects (see Fig. 9). The period-by-period decomposition reveals similar patterns in the influence of local and external shocks on the activity effect. The scale of activities reduced significantly in the subsector during the pandemic. Additionally, the power and economic crises appear to have deteriorated technical efficiency in the subsector, though the same cannot be said for the COVID-19 period. The structural effect was consistently negative except during the pandemic.

Finally, for the health and social work sector (see Fig. 10), long-term analysis shows that combined positive structural and activity effects outweighed the negative intensity effect, leading to increased energy consumption. Similar to other service subsectors, the period-by-period decomposition shows that the activity effect generally slowed during crisis periods, becoming negative during the pandemic, confirming that the pandemic may have had a greater impact on the scale of activities in this subsector than other shocks. Except for the 2013–2015 period, where the intensity effect was positive, it was consistently negative afterward, suggesting improvements in technical efficiency in the sector. This improvement could partly be attributed to the spillover effect of installing automatic capacitor banks (ACB) in selected public health facilities starting in 2013. The structural effect became negative only during the power crisis period.

The decomposition of the service meso sector underscores the importance of recognizing the unique characteristics of these sectors in explaining energy consumption patterns. While all subsectors appear vulnerable during periods of local and external shocks, they vary significantly in whether such shocks impact the scale of activities or technical efficiency. During the power crisis period, all service sector subsectors experienced increased technical inefficiency in energy consumption, particularly the transport and storage subsector. Technical efficiency during the COVID-19 deteriorated more in the transport and storage, and hotels and restaurants subsectors. These heterogeneous patterns among the service meso sectors highlight the importance of considering subsector uniqueness in planning and designing demand management interventions.

5. Conclusion and policy recommendations

This study analyzed total final energy consumption in Ghana from 2013 to 2020 across macro, meso, and micro levels using the additive index decomposition technique. It examined how shocks, such as the power crisis and COVID-19, along with government energy policies explain industrial, service, and agricultural sectors energy consumption. The following key findings emerged from this study.

Energy consumption is influenced by a variety of factors across different sectors, with notable differences in the impact of these factors. External and local shocks, such as the COVID-19 pandemic and power

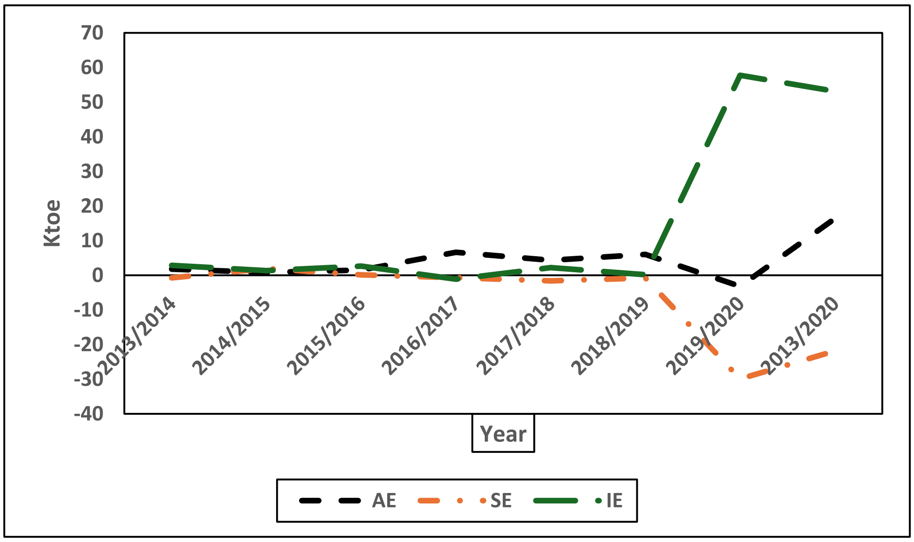

Fig. 7. Additive chain linked and period long decomposition for hotels and restaurants.

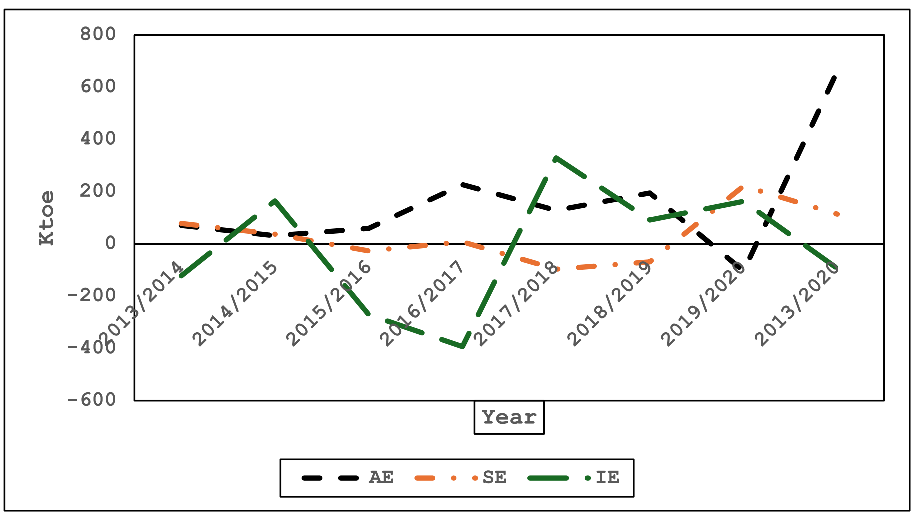

Fig. 8. Additive chain linked and period long decomposition for transport and storage.

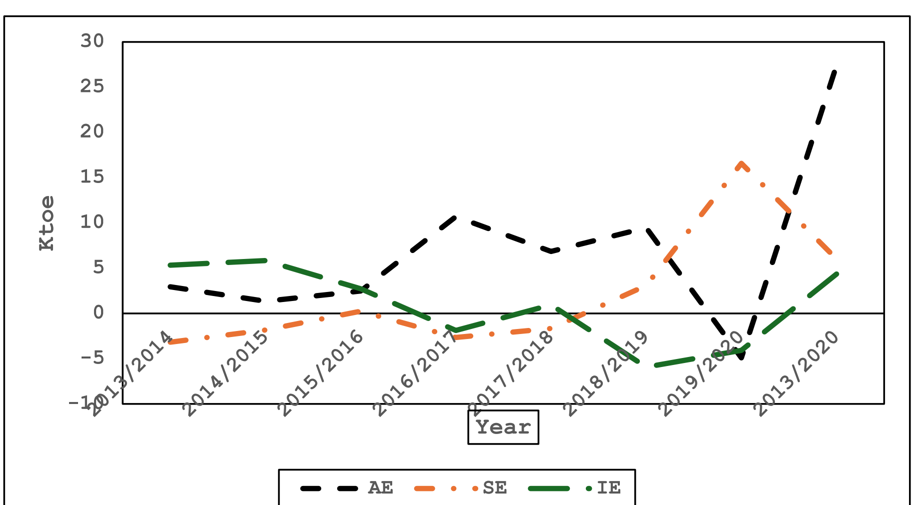

Fig. 9. Additive chain linked and period long decomposition for education.

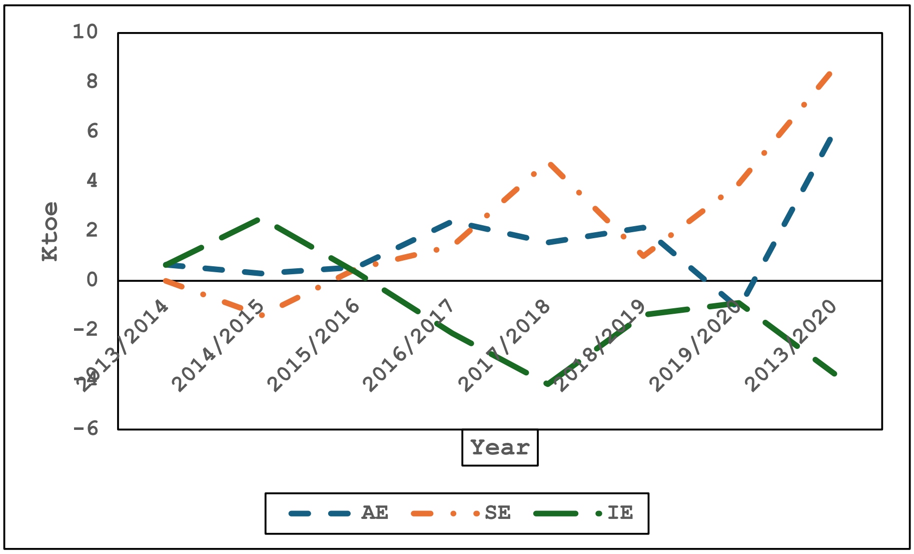

Fig. 10. Additive chain linked and period long decomposition for health and social work.

crises, have altered energy consumption patterns through changes in scale and efficiency.

In the industry and service sectors, subsectors experienced unique impacts from these shocks. Long-term increases in energy consumption in manufacturing, construction, hotels and restaurants, and education were driven by significant inefficiencies, especially during crises. In contrast, mining, transport, and health subsectors improved in technical efficiency over the long term but regressed during crises.

Within the manufacturing sector, certain subsectors like food products, beverages, paper, textiles, and metals experienced increased inefficiencies over time, while others like wood products, rubber, plastics, and chemicals showed improved efficiency. These results indicate that technical inefficiency remained and worsened in some manufacturing subsectors during crisis periods.

The study indicates that local and external shocks can have lasting effects on certain sectors, leading to ongoing technical inefficiencies. Thus, it's important to tailor crisis response strategies and energy demand management interventions to the specific needs of different subsectors to create a sustainable energy economy.

Targeted interventions could help improve technical efficiency in energy consumption. For instance, the mining sector could benefit from incentives to meet international environmental standards, while manufacturing might need specific technical efficiency programs. The hotels, restaurants, food, and beverage sectors could adopt energy efficiency initiatives and sustainable practices. The education sector could implement energy-saving programs suited to its operations.

To protect these programs from adverse shocks, it is crucial to maintain and enhance technical efficiency during crises through support mechanisms like tax holidays, subsidies for energy-efficient technologies, and soft loans. The COVID-19 measures, including free electricity for lifeline consumers and a 50 % rebate for non-lifeline consumers, did not promote energy efficiency investments as they were general austerity measures without ties to energy management. Future austerity measures should be linked to energy efficiency goals to enhance technical efficiency. Moreover, the narrow focus of existing energy efficiency interventions limits their general equilibrium effects.

The study's analysis did not consider all meso and micro sectors, which restricts the generalizability of the results. Future research should include other meso-sectors within the industrial, service, and agricultural macro-sectors as data becomes available. Improved data collection will enable comprehensive analysis, effective policy formulation, and better monitoring and evaluation of energy consumption patterns and shock impacts.

We recognize that the predominantly descriptive analytical approach used in this study limits our ability to make causal claims. To overcome these limitations, more sophisticated methods, such as experimental and quasi-experimental designs and event study techniques, may be necessary.

CRediT authorship contribution statement

Philip Kofi Adom: Conceptualization, Methodology, Software, Data curation, Formal analysis, Writing – original draft, Visualization, Investigation, Supervision, Writing – review & editing. **Goodsgood Kofi Botwe-Koomson:** Conceptualization, Methodology, Software, Data curation, Formal analysis, Writing – original draft, Visualization, Investigation, Writing – review & editing. **William Ohemeng:** Conceptualization, Methodology, Software, Data curation, Formal analysis, Writing – original draft, Visualization, Investigation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

I have attached the data and the computation as a supplementary fileln

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List of Abbreviations

IEA	Internal Energy Agency
SEI	Stockholm Environment Institute
IISD	International Institute for Sustainable Development
UNEP	United Nations Environment Programme
IDA	Index Decomposition Analysis
UNFCC	United Nations Framework on Climate Change
US EIA	United States Energy Information Administration
IPCC	International Panel on Climate Change
OEE	Office of Energy Efficiency
EC	Energy Commission, Ghana
NEECPS	National Energy Efficiency and Conservation Programme
SE4ALL	Sustainable Energy for All
LPG	Liquefied Petroluem Gas
PV	Photovoltaic
MW	Megawatts
RSP	Rooftop Solar Programme
BOS	Balance of System
CEWPs	Certified Electrical Wiring Professionals
CEWIs	Certified Electrical Wiring Inspectors
GDP	Gross Domestic Product
GSS	Ghana Statistical Service
Ktoe	Kilotons of oil equivalent
UNDP	United Nations Development Programme
ISSER	Institute of Statistics, Social and Economic Research
ACB	Automatic Capacity Banks
GW	Gigawatts
KWh	Kilowatts hours

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esr.2024.101549.

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