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MASTER THESIS

Topic:

DRIVERS OF ENERGY CONSUMPTION IN GHANA: A SECTORAL DECOMPOSITION ANALYSIS OF ENERGY SUPPLY AND DEMAND DRIVERS

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by

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DEDICATION

This thesis is dedicated to my family for their love and support.

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Nothing happens successfully without the Almighty God granting it. As a result, I would first express my profound gratitude to the Almighty God for his guidance and protection throughout this master's program.

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ABSTRACT

Energy plays a crucial role in determining Ghana's socioeconomic growth. The rapid growth of demand and the increasing complexities of energy supply in Ghana pose a significant challenge to Ghana’s efforts to a universal energy access.

This thesis is aimed at assessing the drivers of energy consumption in Ghana using a sectorial decomposition of energy demand and supply drivers. It applies the additive Logarithmic Mean Divisia Index (LMDI) to decompose drivers of Ghana's energy consumption between 2000-2020. Activity effect, efficiency, effect, and intensity effect were used to quantify changes in PEC. Changes in FEC were assessed by quantifying the contributions from three different factors: activity effect, structure effect, and intensity effect. The results show that the activity effect and the efficiency effect led to an increase in PEC while the intensity effect led to a decline in PEC. Similarly, FEC increased significantly throughout the period with the activity effect being the major contributor to the increase in consumption. The structure and intensity largely contributed to a drop in final energy consumption. Within the residential sector, the growth of population and the proportion of the population with access to electricity, clean fuels, and those who use traditional biomass were the dominant factors driving FEC while technological improvement in energy intensity was an inhibiting factor to consumption growth. In the industrial sector, the activity effect contributed to FEC growth while structure and intensity effects were inhibitors to consumption growth. The results of this study will help the government to reduce energy consumption by encouraging industrial restructuring and enforcing energy-efficiency and energy-saving policies.

Keywords: LMDI decomposition analysis; energy consumption; intensity effect; activity effect; Ghana energy system.

LIST OF ACRONYMS

LMDI	Logarithmic Mean Divisia Index
BMBF	Bundesministerium für Bildung und Forschung
WASCAL	West African Science Service Center on Climate Change and Adapted Land Use
IEK-STE	Institute for Energy and Climate Research Systems - Research and Technological Development
FZJ	Forschungszentrum Jülich
SDGs	Sustainable Development Goals
IDA	Index Decomposition Analysis
GDP	Gross Domestic Product
GVA	Gross Value Added
UN	United Nations
EC	Energy Commission
POP	Population
GSS	Ghana Statistical Service
TJ	Tera Joule
RE	Renewable Energy
UAM	Université Abdou-Moumouni
MW	Mega Watt
FEC	Final Energy Consumption
PEC	Primary Energy Consumption
POP_b	Population that uses traditional biomass
POP_{ele}	Population with access to electricity

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CHAPTER ONE

1. INTRODUCTION

This chapter presents the context and focus of the study. It comprises the background, problem definition, and justification of the research, which describes the problem and need for research. This chapter also presents the research questions and objectives of this study.

1.1 Background

Ghana’s energy mix is predominantly conventional biomass, a fragile hydropower industry, and imported fossil fuels, which cause concerns about energy security, emissions, and high costs, which have a detrimental influence on economic growth[1], [2]. Like many other nations in sub-Saharan Africa, Ghana has difficulties meeting its energy needs[3]. According to [4], the final energy consumption will increase by 7%-12% annually over the next two decades. The trend in energy consumption is likely to worsen owing to the influx of outdated appliances[5]. These future trends require Ghana to diversify its energy-supply mix while minimizing emissions. This implies that Ghana must explore energy sources that are economically viable, socially fair, and environmentally friendly.

Ghana has huge potential for renewable energy, including bio-energy, solar, wind, hydropower, tidal wave power, and waste-to-energy, which remain underexploited [3, 7]. In recent years, there has been growing interest in renewable energy in Ghana as it seeks to reduce its dependence on imported fossil fuels and improve energy security. The government has set a target to increase the share of renewable energy in the energy mix to 10% by 2030[7] to achieve a more sustainable and diversified energy system. In addition, green hydrogen and its derivatives have emerged as promising substitutes for conventional fossil fuels[9, 10] and have the potential to play a significant role in Ghana's future energy mix. Through electrolysis, clean and carbon-free energy sources can be used to create green hydrogen and its derivatives, such as ammonia, methanol, and synthetic fuels.

1.2 Problem Definition and Justification

Ghana currently faces several energy challenges, including reliance on imported fossil fuels, limited access to electricity in rural areas, and high energy costs. Many key driving factors have influenced Ghana’s total energy consumption, including ever-growing urbanization and population, economic growth, changes in the lifestyles of the population, and governmental policies. This presents the need to assess the extent at which these drivers influence energy consumption to ensure sustainable energy consumption and production.

This study employs a sectoral decomposition analysis of energy supply and demand drivers to identify the key factors contributing to changes in energy consumption in different sectors of the Ghanaian economy. This analysis provides insights into the most effective policy interventions to promote sustainable energy consumption and production in Ghana and the possible integration of green hydrogen and its derivatives into the future final energy mix. Furthermore, this study contributes to the literature on energy demand and supply in Ghana and provides a basis for future research in this area. The results of this study will shed light on the benefits of using green hydrogen and its derivatives in Ghana.

1.3 Objectives of Study

This study aims to fulfil the following objectives:

1. To identify the factors driving energy consumption in Ghana.
2. To assess the extent of the impact of these factors by conducting a sectorial decomposition analysis in terms of demand and supply.
3. To provide policy options for government, energy companies, and stakeholders on how to reduce energy consumption.

1.4 Research Questions

This research seeks to answer the following main question:

1. What are the main drivers of the energy demand and supply in Ghana?
2. How do these drivers affect a country's energy demand and supply?
3. What policy recommendations will promote sustainable energy consumption, production, and integration of green hydrogen and its derivatives in Ghana?

1.5 Conclusion

This chapter introduces the research and provides background information. The problem statement, as well as the justification for the project, has been clearly stated along with the questions and objectives outlined for the research.

CHAPTER TWO

2. LITERATURE REVIEW

This chapter is divided into three sections: The first section provides a general overview of Ghana’s energy sector, trends, and existing installed capacities, and the second section examines Ghana’s demand and supply outlook. The last section reviews the studies that have applied the decomposition methodology.

2.1 Overview of Ghana’s Energy Sector: Trends, and Existing Generation Systems

Ghana faces challenges in achieving its Sustainable Development Goals (SDGs) owing to insufficient energy supply caused by factors such as rapid population growth, urbanization, changes in lifestyle, and economic structure[3, 11]. Before the Akossombo Dam was built, Ghana's power supply was from isolated diesel-generating plants situated close to crucial load centres [11]. The dam was constructed between 1961 and 1965 with funding from the World Bank, United the Kingdom, and the United States[2]. Its generating capacity increased from 588 to 912 MW in 1972. The Kpong Hydroelectric Dam, built between 1977 and 1982, has a capacity of 160 MW[11]. The power generation from these dams is heavily influenced by the seasonal cycles. Thermal power generation was introduced in 1997 as a complement to traditional hydroelectricity following the 1983 drought[2], which emphasized the need to diversify Ghana's energy-generation system. In 2000, two 110 MW combustion turbine plants were added to the Takoradi Thermal Power Station (TAPCO), expanding its capacity from 330 to 550 MW[11]. This marked Ghana's initial steps towards transitioning to thermal energy generation.

The figure below shows the percentage share of electricity generation by fuel type from 2000 to 2021.

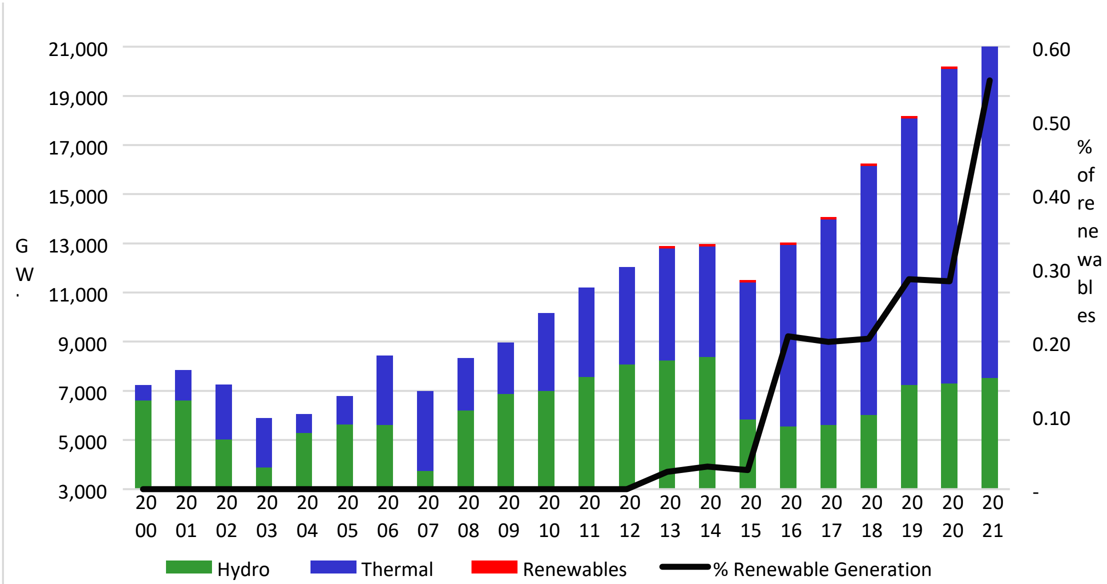


Figure 1: Electricity Generation (2000-2021)

Source: [4]

In 2000, hydropower plants generated 92% of Ghana's electricity, whereas thermal plants generated only 8%. As of 2021, the energy blend includes a mix of 0.55% renewables, 34.1% hydro energy, and 65.3% thermal energy[4]. The table below shows existing energy systems with their installed and dependable capacities. Table 2.1 below shows the installed generating capacity of power in Ghana.

Table 2. 1: Installed Generation Capacities in Ghana as of 2021 (MW)

Plant	Installed Capacity	Dependable Capacity
Hydro Power Plants		
Akosombo	1,020	900
Kpong	160	140
Bui	404	360
Sub-total	1,584	1,400
Thermal Power Plants		
Takoradi Power Company (TAPCO)	330	300
Takoradi International Company (TICO)	340	320
Tema Thermal 1 Power Plant (TT1PP)	110	100
Tema Thermal 2 Power Plant (TT2PP)	87	70
Cenit Energy Ltd	110	100
Kpone Thermal Power Plant	220	200
Ameri Plant	250	230

Sunon Asogli Power (Ghana) Ltd	560	520
Karpowership	470	450
Trojan	44	39.6
Amandi	203	190
AKSA	370	350
Cenpower	360	340
Early Power / Bridge	144	140
Genser	155	131
Sub-total	3,753	3,480.6
Other Renewables		
On-grid		
VRA Solar (Navrongo)	2.5	2
VRA Solar (Lawra)	6.5	4.5
VRA Solar (Kaleo)	13	10
BXC Solar	20	16
Meinergy	20	16
Bui Solar	51	46
Safisana Biogas	0.1	0.1
Tsatsadu Hydro	0.05	0.05
Distributed Solar PV	30.9	-
Sub-total	144.05	94.65
Off-grid		
Solar	7.42	-
Wind	0.02	-
Sub-total	7.44	-
Mini-grid		
Solar	0.314	-
Wind	0.011	-
Sub-total	0.325	-
Total Renewables	119.865	94.6
Total	5,488.82	4,975.25

Source: [4]

Thermal plants operate on different types of fossil fuels that contribute to greenhouse gases in the atmosphere. They are worst affected when there is a shortfall in the gas supply. A clear instance is the Russia-Ukraine War, which disrupted the gas supply and caused a surge in gas prices.

2.2 Energy Demand and Supply Outlook in Ghana

Various governments have prioritized the energy industry in their policies, including those that assure environmentally friendly energy production and use and increase access to affordable modern energy sources[12]. However, the country is still unable to meet its energy needs independently. Statistics from the Energy Commission show that the total dependable installed capacity as of 2021 is 43,538,190 MWh, while the total energy consumption is 108,682,350 MWh. This implies that Ghana generates only approximately 40% of the total energy consumed. To lessen its dependency on imported fossils, the local generation needs to be prioritized. Per[4], Ghana's total energy supply mix is mainly biomass, oil, and natural gas, accounting for 34%, 35%, and 26% of the total supply in 2021. The figure below shows the total energy supplied by the fuel in Ghana.

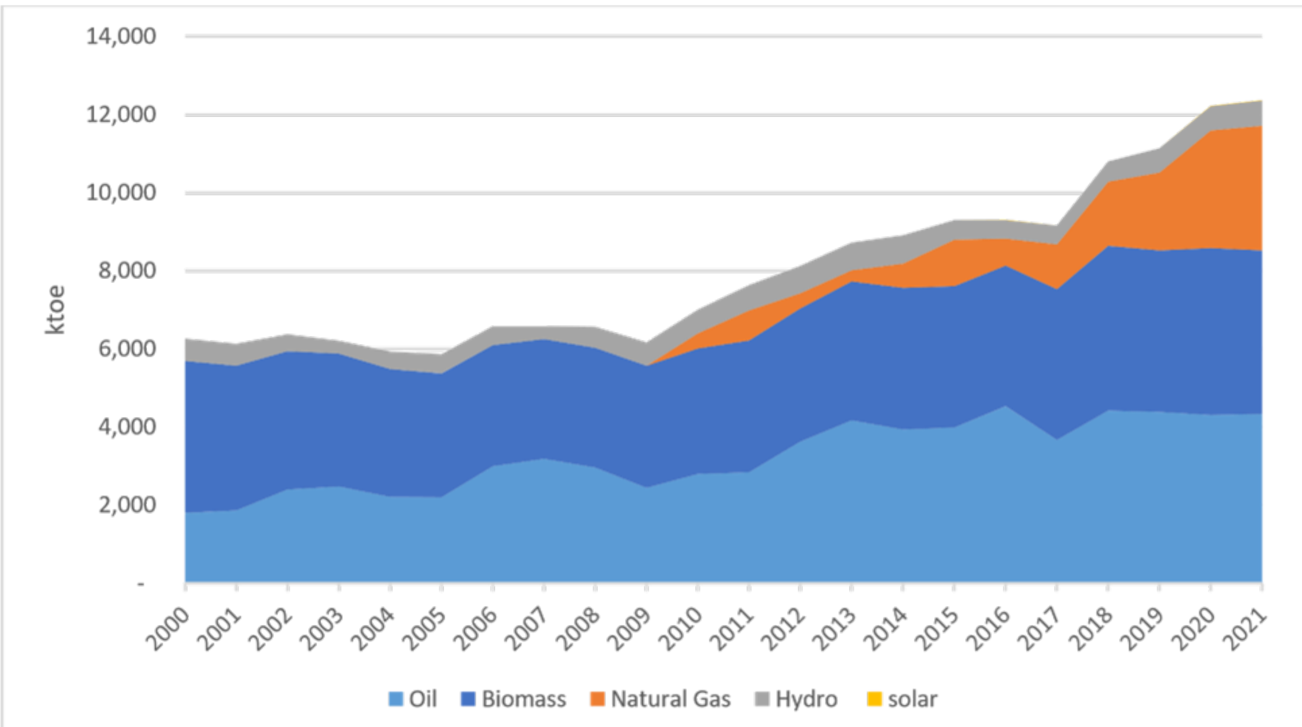


Figure 2: Total energy supply by fuel

Source: [4]

Energy demand in Ghana is expected to surge because more firms will expand and households will become richer with an increasing population and industrialization. Energy demand is expected to increase by 7%-12% annually over the next two decades[10], and this will present a significant energy challenge to Ghana despite improvements in generation capacity. [4] also projected that peak electricity demand has been increasing at an annual rate of 9.2% since 2016. All these projections present a clear need for Ghana to explore diverse sustainable low-carbon energy-generating sources to meet growing demand. As a signatory to the Paris Agreement, the exploration of these sources must be environmentally friendly and contribute to reducing Ghana's greenhouse gas emissions. Figure 2.3 shows the main energy consumers in Ghana categorized into sectors (residential, industrial, agricultural, transport, and service).

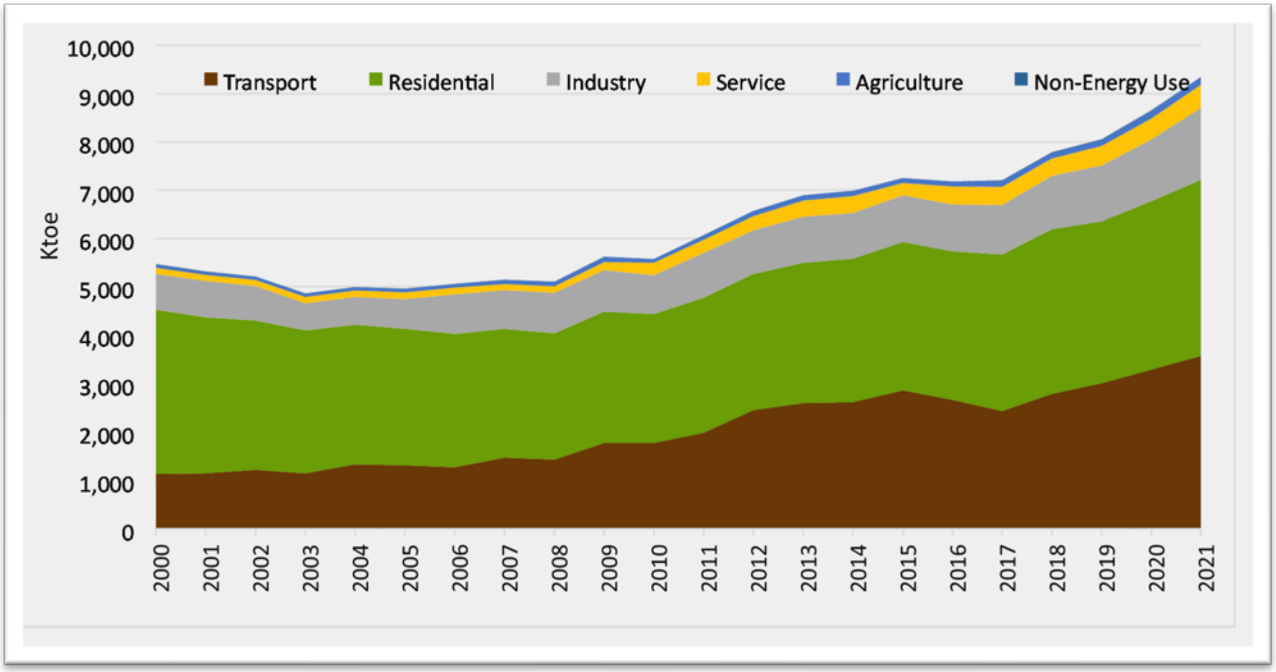


Figure 3: Total energy consumed by sectors

Source: [4]

2.3 Decomposition Analysis

Several studies have used index decomposition analysis (IDA) frameworks to analyse drivers of changes in energy consumption, CO_2 emissions, energy efficiency, and many other variable indicators[13];[14];[15];[16][17][18]. [20] used the Logarithmic Mean Divisia Index (LMDI) approach of IDA frameworks to examine the factors influencing CO_2 emissions from the industrial sector of Fujian province, China. Decomposition analysis between 2005 and 2016 revealed industrial scale effect was the main driving factor of CO_2 emissions, while the energy intensity effect was the main inhibitor. This structural effect had a minimal impact on CO_2 emissions in the Fujian industrial sector. [21] focused on examining CO_2 emissions from electricity generation in China during the 1991-2001 time period using the LMDI approach. The findings showed that the economic activity effect was the main contributor to CO_2 emissions from electricity generation, whereas the generation efficiency effect was the main inhibitor of CO_2 emissions. [22] explored the changes in energy intensity in Latvia using LMDI methods for the energy sectors. The increased energy intensity is attributed to the expansion of the energy-demanding sectors. The scale, composition, emission regulation, and production efficiency influence CO_2 emissions in the production of Indian exports [23]. The study decomposed data within the 1995-2009 period and found that the scale effect increased CO_2 emissions by more than 184%. However, the other three effects had a dampening effect on CO_2 emissions. [24] discussed the factors affecting changes in energy consumption and investigated energy intensity across the Indonesian manufacturing sector from 1980 to 2015. The results showed that limited changes in the industrial structure contributed to a 65% reduction in energy intensity over the study period. Energy efficiency improvements and financial shocks also influence energy intensities. Other studies have employed a similar methodology to investigate trends in other variable indicators, as shown in Table 2.2.

Table 2. 2: Representative literature for LMDI decomposition analysis

Indicator	Frameworks			Driving effects				Source(s)
	Region	Study period	Sector	Activity effect	Structure effect	Intensity effect	Others	
Energy Intensity	Australia	1978-2009	Economy-wide	X	√	X	Efficiency effect	[25]
	Ghana	2000-2020		X	√	X	Labor productivity	[26]
Electricity Consumption	China	1995-2014	Economy-wide	√	X	√	Energy consumption effect	[27]
		1990-2015	Manufacturing	X	√	√	Transfer effect	[28]
CO_2 Emissions	46 cities	1960-2001	Transport	X	√	X	urbanization effect	[29]
	40 countries	1995-2009	Economy-wide	X	√	√	X	[30]
	USA	2000-2016		X	√	√	Labor input effect	[31]
	Thailand	2005-2017	Manufacturing	X	√	√	X	[32]
	China	2009-2018	Power	√	√	√	X	[33]

	China	1985-2009	Transport	√	√	√	Transportation modal shifting effect	[34]
	Shanghai, China	1996-2007	Industrial	X	√	√	industrial output	[35]
	Korea	1991-2009	Manufacturing	√	√	√	emission-factor effect.	[36]
Energy Consumption	Kerala, India	2007-08 to 2016-17	power and petroleum sector	√	X	√	X	[37]
	South Africa	1970-2016	Manufacturing	√	√	√	X	[38]
	EU Countries	2005-2016	Economy-wide	√	X	X	Demographic effects, changes in lifestyle, weather	[39]
	Korea	1991-2001	Manufacturing	√	√	√	X	[40]

	China	2000-2014	Non-ferrous metal industry	X	√	√	labour productivity effect and industrial scale effect.	[41]
Carbon Intensity	China	2001-2015	Urban residential	X	X	√	urban sprawl, and land demand	[42]
Water and Energy Consumption	China	2011-2015	Economy-wide	√	√	√	industrial water consumption	[43]

CHAPTER THREE

3. DATA AND METHODOLOGY

3.1 General Formulae of LMDI

The LMDI decomposition analysis method is widely used because of its desirable features, including the ability to provide perfect decomposition, consistency in aggregation, and the ability to express components in additive or multiplicative forms [44].

Assume Z is an aggregate variable, and there are m factors (X1, X2, X3…Xm) that influence Z over some time. The general IDA identity is given by

$$Z = \sum_{j} Z_j = \sum_{j} Z_1, j \ Z_2, j \, Z_3, j \dots \dots \dots . Z_3, j \qquad [1]$$

The contribution of the mth factor to the change in the aggregate from a reference time, t to a time, T is expressed as;

$$\Delta Z_{xm} = \sum_j L\left(Z_j^T, Z_j^t\right) In[\frac{X_{m,j}^T}{X_{m,j}^t}] = \sum_i \frac{Z_j^T - Z_j^t}{InZ_j^T - InZ_j^t} In\left[\frac{X_{m,j}^T}{X_{m,j}^t}\right] \qquad [2]$$

Where L (a, b) = (a-b) / (lna – lnb)

3.2 Decomposition of Energy Consumption

The general IDA identity for the decomposition of energy consumption is given by

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{E} = \sum_i Q S_i \, I_i \qquad [3]$$

Where i denotes the sector, E is the total energy, Q is the economic activity (gross domestic output or gross added value), $and \ S_i = \frac{Q_i}{Q}$ represents the proportion of the economic activity relative to the whole economy in which the structural effect is captured. $I_i = \frac{E_i}{Q_i}$ is the total energy intensity of sector i which captures the intensity effect.

In the additive LMDI approach, the change in energy consumption due to the activity, structure, and intensity effects from a reference time t to time T is calculated as follows:

$$\Delta E = E^T - E^t = \Delta \mathrm{Eact} + \Delta \mathrm{Estr} + \Delta \mathrm{Eint} \qquad [4]$$

Where;

ΔEact, ΔEstr, and ΔEint are the changes due to activity, structure, and intensity effects which are respectively represented by Q, S_i, and I_i in equation [3] above. The following formulae were used to quantify the above effects:

$$\Delta \text{Eact} = \sum_i w_i \, In\left(\frac{Q^T}{Q^t}\right) \quad [5a]$$

$$\Delta \text{Estr} = \sum_i w_i \; In\left(\frac{S_i^T}{S_i^t}\right) \quad [5b]$$

$$\Delta Eint = \sum_i w_i \; In\left(\frac{I_i^T}{I_t^t}\right) \quad [5c]$$

$$wi = \frac{E_i^T - E_i^t}{InE_i^T - InE_i^t}$$

3.2.1 Decomposition of Primary Energy Consumption (PEC)

The primary energy consumed was decomposed using the following decomposition identity:

$$PEC = GDP \frac{PEC}{FEC} \frac{FEC}{GDP} \quad [6]$$

Where GDP denotes the activity effect, PEC/FEC the efficiency effect, and FEC/GDP the intensity effect.

3.2.2 Decomposition of Final Energy Consumption of Industrial Sector

The division of industrial subsectors was performed based on available disaggregation data on energy consumption. As a result, this study considered five industrial subsectors (manufacturing, mining and quarrying, services, transport and agriculture). Due to data unavailability and restrictions, it was not possible to treat the transport sector separately. To simplify this problem, this sector was integrated into the industry sector. The equation used to decompose the final energy consumption in the industrial sector is as follows:

$$\text{FEC} = \sum_i GVA \frac{GVA_i}{GVA} \frac{FEC_i}{GVA_i} = GVA \frac{GVA_{man}}{GVA} \frac{FEC_{man}}{GVA_{man}} + GVA \frac{GVA_{ser}}{GVA} \frac{FEC_{min}}{GVA_{min}} + GVA \frac{GVA_{agr}}{GVA} \frac{FEC_{agr}}{GVA_{agr}} + GVA \frac{GVA_{ser}}{GVA} \frac{FEC_{ser}}{GVA_{ser}} + GVA \frac{GVA_{trp}}{GVA} \frac{FEC_{trp}}{GVA_{trp}} \quad [7]$$

where i represents the disaggregated subsectors, and FEC and GVA are the final energy consumption and gross added value of the industrial sector, respectively. Similarly, GVA_i and FEC_i are the gross added values and final energy consumptions for the different subsectors of the industrial sector considered.

3.2.3 Decomposition of Final Energy Consumption of Residential Sector

The residential energy demand is mainly influenced by an increasing population (households). The final residential energy consumed was decomposed into various fuel types by using the following decomposition identity:

$$FEC = FEC_{r,b} + FEC_{r,ele} + FEC_{r,cf} = POP \frac{POP_b}{POP} \frac{FEC_{r,b}}{POP_b} + POP \frac{POP_{ele}}{POP} \frac{FEC_{r,ele}}{POP_{ele}} + POP \frac{POP_{cf}}{POP} \frac{FEC_{r,cf}}{POP_{cf}} \quad [8]$$

Where POP and FEC are the population and final energy consumption of the residential sector. $FEC_{r,b}$ $FEC_{r,ele}$, and $FEC_{r,cf}$ respectively represent the final energy consumed in the residential sector from traditional biomass, electricity, and clean fuels. Similarly, POP_b, POP_{ele}, and POP_{cf} represent the population that use the biomass, the population with electricity access, and the population that uses clean fuels for cooking.

Table 3. 1: Overview of decomposition identities used in this study

Sector	Industry	Residential
(Index=i)	1. Manufacturing 2. Mining and Quarrying 3. Agriculture 4. Services 5. Transportation	1. Electricity 2. Traditional biomass 3. Clean fuels
Activity effect	Gross Value Added (GVA)	POP
Structure effect	$GVAi/GVA$	POPi / POP
Intensity effect	$FECi/GVAi$	$FECi/$ POPi

i denote the subsector

FEC = final energy consumed in the residential sector

POP = total population

GVA = total gross added value

GVAi = gross added value per each subsector

FECi = final energy consumed per each subsector

POPi = population with or without access to electricity

3.3 Data Sources

Primary and Final energy consumption data were obtained from the Ghana Energy Commission (EC) and the UN Statistics website, a public database that provides time-series data for different sectors between 2000 and 2020. UN Data comprises data from various national sources that have been harmonized to enable comparability of data across different countries. Economic activity data were obtained from the World Bank's database. Data from the Ghana Statistical Service (GSS) were used to cover specific data needs, such as population and population with access to electricity.

3.4 Data Overview

Owing to data unavailability and restrictions, simplifications and approximations were performed to fill out missing data.

Industrial Sector:

FEC for the manufacturing, construction, and non-fuel mining industries was used. However, its corresponding activity data was unavailable. Therefore, activity data for manufacturing alone.

FEC for mining and quarrying was used. However, its corresponding data was not available. The activity data used for mining and quarrying in this study were for mineral rents. Even so, data from 2000-2014 were missing and had to be filled using a simple ratio and proportion method.

FEC for the transportation sector was used. The activity data for transportation was retrieved from the World Bank website as a percentage of services imports and BoP. However, it was difficult to obtain data on service imports and BoP for Ghana. Therefore, transport activity was calculated as a percentage of GDP.

Residential Sector

The population without access to electricity was assumed to be the population that uses traditional biomass for cooking.

The FEC for the population that has access to clean fuels was not readily available. Therefore, the FEC for oil products was used as the FEC for instead.

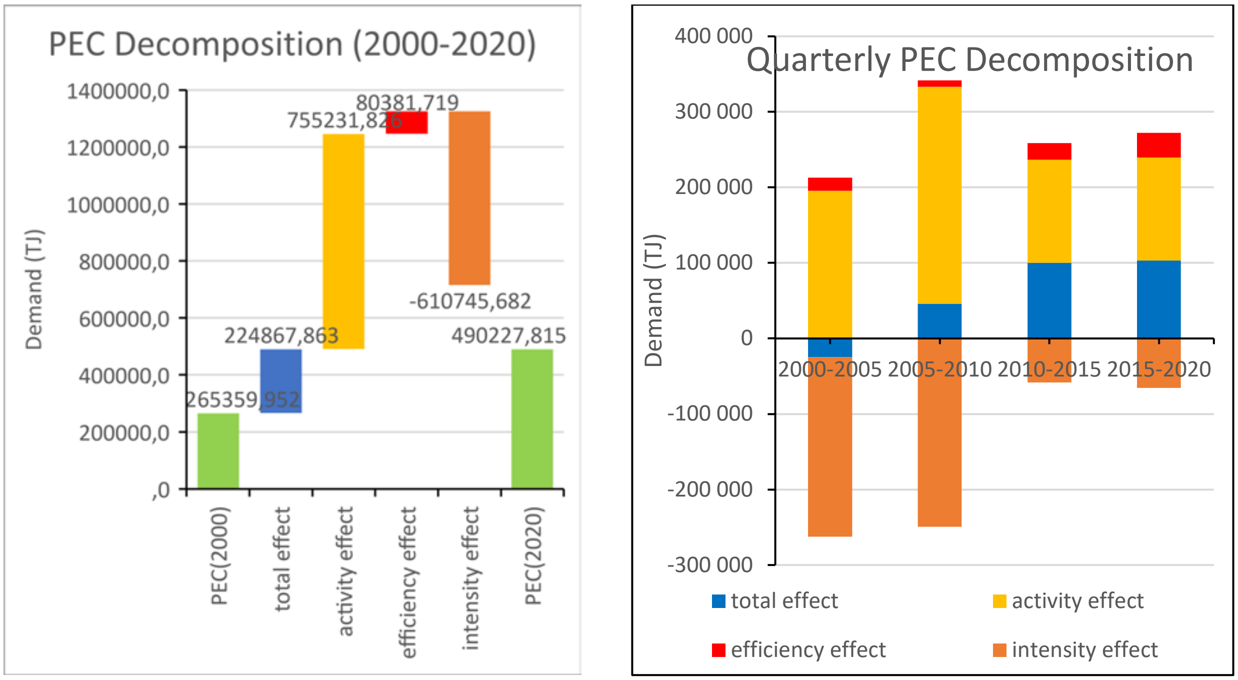
CHAPTER FOUR

4. RESULTS AND DISCUSSION

The additive LMDI analysis was performed using Excel 2016. Activity, efficiency, and intensity effects were used to analyse primary energy consumption (PEC). PEC increased from 265,360 TJ in 2000 to 490,228 TJ in 2020. This is consistent with a previous study [44] which asserts that increased PEC is as a result of economic growth. The activity effect between this period was positive and contributed to an increase in primary energy consumption by 755,232 TJ. This implies that the increase in primary energy consumption was primarily due to GDP growth which is in line with the findings of [45] and [25]. In the same period, the efficiency effect also contributed to an increase in primary energy consumption by 80,382 TJ. This increase in energy consumption could indicate worsening impacts of transformational losses, which could be a signal of aging energy infrastructure. The activity effect is the growth rate of GDP and the efficiency effect is the ratio of primary energy consumption to final energy consumption. The increase in primary energy consumption due to the activity effect was 9 times higher than the increase due to the efficiency effect. The intensity effect contributed to a drop in primary energy consumption by 610,744 TJ owing to improvements in technology. Table 4.1 below show the additive LMDI decomposition results for PEC from 2000 to 2020. Figure 4(a) shows the contributions of the various influencers while Figure 4(a) shows the decomposition in quarterly terms.

Table 4. 1: Additive Decomposition results of PEC between 2000-2020

Period	total effect	activity effect	efficiency effect	intensity effect
2000-2001	177	17,032	9,914	-26,769
2001-2002	-4,516	39,519	361	-44,396
2002-2003	-8,512	54,529	15,804	-78,845
2003-2004	-4,365	37,977	-1,402	-40,939
2004-2005	-7,603	46,464	-7,432	-46,634
2005-2006	29,633	169,697	23,360	-163,425
2006-2007	-1,213	46,576	4,007	-51,796
2007-2008	-1,605	38,654	4,459	-44,718
2008-2009	-15,084	-24,982	-53,007	62,906
2009-2010	34,444	57,041	29,798	-52,395
2010-2011	31,958	60,566	-8,505	-20,102
2011-2012	33,107	16,042	4,158	12,907
2012-2013	4,407	148,720	2,543	-146,857
2013-2014	15,742	-49,850	12,229	53,362
2014-2015	15,046	-39,144	11,706	42,484
2015-2016	-10,717	48,864	-7,088	-52,493
2016-2017	-13,697	26,945	-14,478	-26,163
2017-2018	62,715	42,456	30,787	-10,527
2018-2019	18,346	6,661	3,900	7,784
2019-2020	46,604	11,463	19,268	15,872



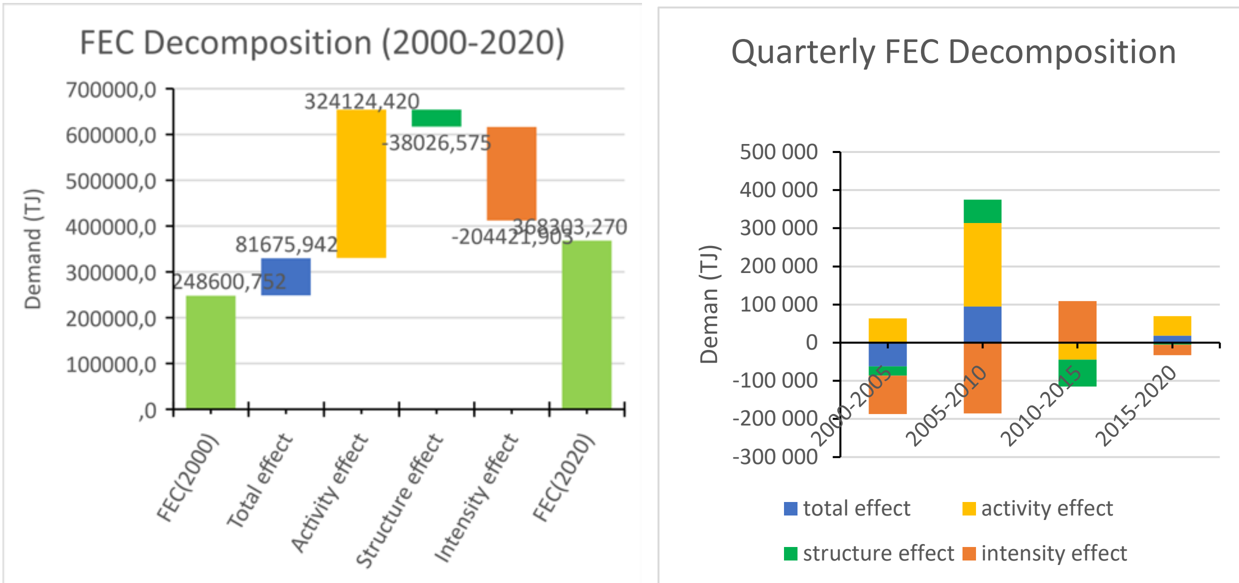
(a) (b)

Figure 4: PEC decomposition

In final terms, activity, structure and intensity effects were used to analyse final energy consumption. Final energy consumption increased from 243,501 in 2000 to 368,303 TJ in 2020 representing a 51.25% increment. This increase is close to the projections of [46] and [47] that estimates final energy consumption growth by 7%-12% annually over the next two decades. As shown in Table 4.2, the activity effect played a role in promoting final energy consumption growth by 324,124 TJ. In the same period, both structure and intensity effects were -38,027 TJ and -204,422 TJ respectively and played inhibitory roles to the growth of final energy consumption. The intensity effect was approximately 5 times larger than the structure effect which implies that the role played by the intensity effect in inhibiting final energy consumption growth was stronger. The intensity effect was a main inhibitor to industrial final energy growth contributing 144,368 TJ drop in energy consumption. Strong energy intensity was observed between 2014-2015 period. This period was characterized by the unstable power supply popularly known as ‘dumsor’ and strong economic growth respectively. The energy consumption intensity played major inhibitory role to energy consumption except in recent times (from 2016-2017 to 2018-2019) when it showed a positive trend. This trend is consistent with the findings of [25] which asserted energy consumption intensity has a positive relationship with economic growth. In effect, the increase in GDP was the major promoter of final energy consumption while improvements in technologies and energy utilization efficiency measures greatly inhibited energy consumption growth. Table 4.2 below illustrate the decomposition results of FEC. Figures 5(a) and (b) show the contributions of the various drivers of final energy consumption in Ghana. In Figure 5(b), the contribution of the activity effect to total final energy consumption was negative. This was so because of the power crisis which spanned 2012-2015 impacting economic activities.

Table 4. 2: Additive Decomposition results of FEC between 2000-2020

Period	Total effect	Activity effect	Structure effect	Intensity effect
2000-2001	-2,845	17,484	3,210	-23,539
2001-2002	6,528	32,330	7,926	-33,728
2002-2003	-24,106	19,388	-5,558	-37,936
2003-2004	4,115	23,619	5,931	-25,435
2004-2005	-2,951	-14,631	-27,855	10,273
2005-2006	30,081	112,365	24,849	-107,133
2006-2007	1,777	26,597	5,631	-30,451
2007-2008	-18,094	5,659	-11,344	-12,409
2008-2009	47,277	15,519	12,629	19,129
2009-2010	18,276	53,256	21,065	-56,045
2010-2011	47,539	48,155	14,523	-15,139
2011-2012	10,145	268	-15,088	24,965
2012-2013	30,768	104,636	31,465	-105,333
2013-2014	14,635	-13,639	11,664	16,610
2014-2015	-122,748	-183,505	-125,483	186,240
2015-2016	36,224	82,462	39,265	-85,503
2016-2017	-6,416	-26,813	-23,071	43,468
2017-2018	21,810	7,343	-8,662	23,129
2018-2019	-209	-9,268	-13,570	22,629
2019-2020	52,170	71,321	42,384	-61,535



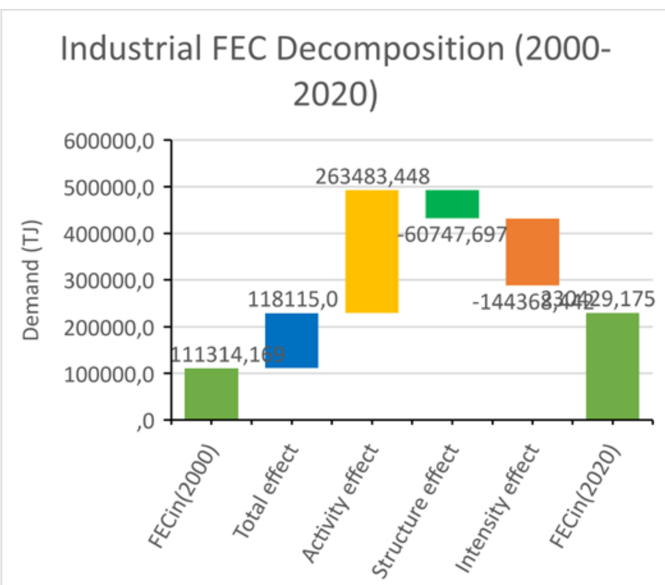
(a) (b)

Figure 5: FEC Decomposition

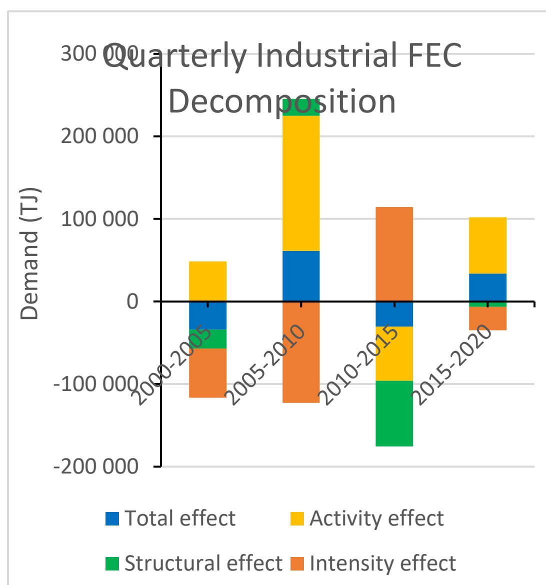
Industrial final energy consumption surged from 111,314 TJ in 2000 to 230,429 TJ in 2020. Consistent with the findings of [12], the growth of industrial GVA led to an increase in industrial energy consumption. [48] studied energy efficiency in Ghana and found that the industry sector in Ghana contributes to energy consumption and will continue to increase, posing a challenge to both energy security and meeting its Paris Agreement goals. The activity effect was positive and contributed to an increase in industrial final energy consumption by 263,428 TJ. Within the same period, the structure effect had an oscillating effect on industrial energy consumption resulting in a decline in final energy consumption by 60,748 TJ. The intensity effect also led to a decline in energy consumption by 230,429 TJ. However, the inhibitory role of structure effect on industrial final energy consumption was approximately 2 times lower than the intensity effect. The activity effect was the GVA growth rate of the industrial sector and the structure effect was the proportion of the industrial sector. In effect, the increase in industrial final energy consumption within this period was primarily due to rapid industrial GVA growth. Figures 6(a) illustrate the contribution of the various influencers of industrial final energy consumption. Figure 6(b) shows a quarterly decomposition of the drivers of energy consumption.

Table 4. 3: Additive Decomposition results of Industrial FEC between 2000-2020

Period	Total effect	Activity effect	Structure effect	Intensity effect
2000-2001	-7,666	4,633	-2,239	-10,060
2001-2002	7,437	20,502	2,628	-15,693
2002-2003	-28,145	8,689	-11,215	-25,619
2003-2004	-2,128	11,143	-3,446	-9,825
2004-2005	-3,504	3,672	-8,648	1,471
2005-2006	10,609	82,965	2,310	-74,666
2006-2007	1,531	20,433	2,237	-21,139
2007-2008	-16,183	-2,372	-13,690	-121
2008-2009	40,325	9,360	11,103	19,862
2009-2010	25,001	53,152	18,549	-46,701
2010-2011	41,151	44,986	18,014	-21,850
2011-2012	18,853	5,019	-3,462	17,296
2012-2013	19,330	89,964	20,437	-91,071
2013-2014	11,807	-20,899	9,323	23,382
2014-2015	-121,526	-184,530	-123,908	186,912
2015-2016	31,436	76,924	34,772	-80,260
2016-2017	-48,279	-45,562	-43,023	40,305
2017-2018	5,175	-18	-14,777	19,970
2018-2019	-3,723	-13,601	-17,015	26,893
2019-2020	49,091	50,693	33,526	-35,128



(a)



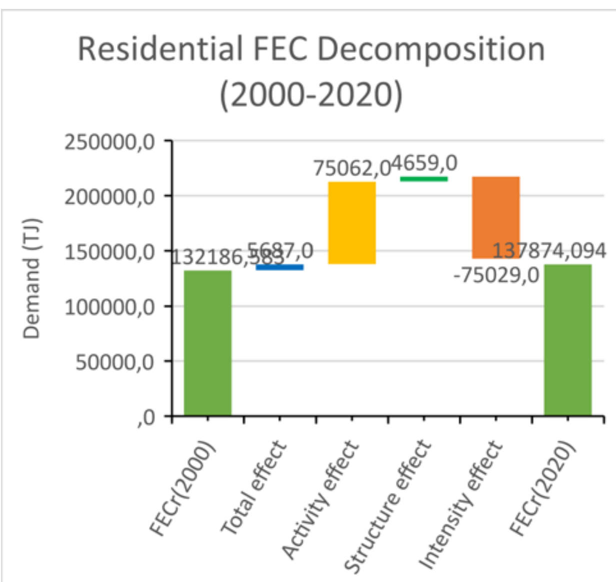
(b)

Figure 6: Industrial FEC Decomposition

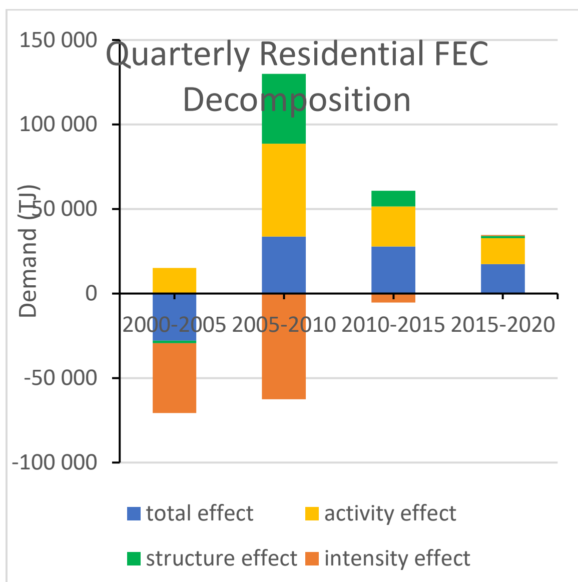
Residential energy consumption increased from 132,187 TJ to 137,874 TJ. Activity effect considered was population and the structure effect was the proportion of the population with and without access to electricity as well as those with access to clean fuels. The activity effect as shown in Table 4.4 was positive and played a major role in promoting residential energy consumption by 75,062 TJ. Increased population leads to increased urbanization which promotes residential energy growth. However, this increase was offset by the structure effect which led to a decline in residential energy consumption by 4,659 TJ. The increase in residential energy consumption can also be attributed to the increase in population with electricity access. As the electricity access rate increases, lifestyle choices change. Also, [25] and [49] in their studies assert that population growth can lead to an increase in household income, which can increase residential energy consumption due to social lifestyle changes. The demand for electricity to power residential appliances surged leading to an increase in final energy consumption. Though increasing electricity access rate increases residential electricity demand, this was compensated by energy efficiency measures and appliance efficiency standards such as measures prohibiting the influx of ‘second-hand’ domestic appliances. The intensity effect led to a decline in energy consumption by 75,029 TJ. Figures 7 (a) and (b) shows the contributions of the drivers of residential energy consumption throughout the period and in quarterly terms respectively.

Table 4. 4: Additive Decomposition results of Residential FEC between 2000-2020

Period	Total effect	Activity effect	Structure effect	Intensity effect
2000-2001	-178	6,951	3,350	-10,479
2001-2002	-3,926	8,828	5,281	-18,035
2002-2003	-650	6,999	3,678	-11,328
2003-2004	1,581	8,574	5,417	-12,410
2004-2005	-24,618	-16,303	-19,327	11,012
2005-2006	23,501	29,430	26,539	-32,468
2006-2007	-54	6,164	3,394	-9,611
2007-2008	3,114	8,032	5,370	-10,288
2008-2009	4,951	4,158	1,526	-733
2009-2010	2,249	7,100	4,515	-9,366
2010-2011	12,379	3,169	509	8,701
2011-2012	-4,708	-4,751	-7,625	7,668
2012-2013	16,754	16,972	14,038	-14,256
2013-2014	4,827	7,260	4,340	-6,773
2014-2015	-1,499	1,025	-1,852	-673
2015-2016	3,056	5,528	2,673	-5,145
2016-2017	5,863	2,749	-48	3,162
2017-2018	6,574	3,101	315	3,158
2018-2019	-2,386	2,332	-455	-4,263
2019-2020	4,255	1,652	-1,140	3,743



(a)



(b)

Figure 7: Residential FEC Decomposition

4.1 Policy Recommendations

The activity effect is the major promoter of energy consumption. However, reducing the activity effect to reduce Ghana's energy consumption is not the best approachBased on the above results, the following policy recommendations for reducing energy consumption in Ghana should be encouraged.

1. Encouraging the integration of renewable energy, green hydrogen, and its derivatives into the energy mix: Renewable energy can be installed at the point of energy consumption. This allows for a more decentralized energy system and therefore reduces or eliminates transmission losses. Therefore, to reduce energy consumption by improving efficiency, Ghana could encourage the use of renewable energy technologies in both residential and industrial sectors. Encouraging the public could go hand in hand with proper incentives to encourage the use of RE systems and the implementation of energy efficiency measures.
2. Changing the economy's structure from high-intensive sectors (manufacturing, mining) to less intensive (service) ones. This could be done by targeting sectors whose economic activities have higher added value compared to energy consumption.
3. Enforcing strict energy efficiency policies: The influx of less standard energy-intensive appliances contributes to an increase in (residential) energy consumption. Curbing this menace will reduce energy consumption in Ghana. Therefore, the government must establish policies that target energy savings, reduce losses, and address aging energy infrastructure
4. Education on demand management: The government could roll out public awareness campaigns to educate the public about energy conservation, efficient utilization, and the benefits of reducing energy consumption.

CHAPTER FIVE

5. CONCLUSION

This study applied the additive approach of LMDI decomposition analysis to decompose Ghana's energy consumption from 2000 to 2020 and analysed the contributions of three main factors to changes in energy consumption (activity effect, structure effect, and activity effect). The findings of this study reveal several key drivers, including economic growth, population expansion, industrial development, and the relative lack of energy-efficient technologies. Acknowledging these factors is pivotal for formulating effective energy policies that can address the mounting energy demand while simultaneously ensuring sustainable development and environmental conservation. The analysis also indicates an oscillating pattern in energy intensity in Ghana promoted by structural effect and labour productivity. Energy efficiency has not been the focus on energy policies. Policymakers can use this information to develop policies that promote energy efficiency and reduce energy consumption in Ghana.

Moreover, the identified disparities in energy consumption among different sectors emphasizing the need for tailored, sector-specific strategies. While the industrial sector appears to be the major contributor to overall energy consumption, the residential sector also plays significant role, necessitating targeted interventions to promote energy efficiency and conservation at all levels. Encouraging behavioural changes, promoting energy-saving practices, and incentivizing the adoption of green technologies can effectively curb wasteful energy consumption and foster a culture of responsible energy usage across all sectors of the economy.

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APPENDIX

APPENDIX B: INPUT DATA

	Industrial FEC (TJ)					
i=1	Manufacturing					
i=2	Mining and quarrying					
i=3	Agriculture, forestry, and fishing					
i=4	Services					
i=5	Transportation					
	i=1	i=2	i=3	i=4	i=5	TOTAL
2000	39,538	19,442	7,188	5,065	40,081	111,314
2001	36,313	16,850	7,231	5,149	40,344	105,887
2002	36,587	17,442	7,535	5,316	43,815	110,696
2003	30,932	7,777	2,327	5,526	47,205	93,766
2004	30,604	6,480	2,663	5,651	49,687	95,085
2005	32,134	10,369	2,618	6,070	49,038	100,228
2006	36,312	14,257	2,659	5,735	49,565	108,527
2007	32,591	14,257	2,835	5,442	52,696	107,821
2008	32,658	12,961	2,749	5,651	51,309	105,328
2009	36,949	19,442	3,618	6,907	67,634	134,550
2010	36,907	20,923	3,707	10,591	68,874	141,002
2011	34,047	25,996	4,752	11,218	88,125	164,139
2012	36,287	27,108	5,800	11,972	105,287	186,454
2013	37,373	19,442	6,057	13,814	108,660	185,346
2014	36,444	20,738	6,103	14,860	109,685	187,830
2015	40,831	15,554	2,149	10,549	121,130	190,213
2016	40,822	16,039	1,933	15,404	112,678	186,877
2017	42,749	17,874	2,264	15,781	102,951	181,620
2018	46,402	19,471	2,574	15,070	118,055	201,573
2019	48,272	19,803	2,770	16,786	127,233	214,864
2020	50,969	19,317	3,041	18,125	138,976	230,429

INDUSTRY ACTIVITY						
	GVA in US$ Billion					
	i=1	i=2	i=3	i=4	i=5	TOTAL
2000	0.45	0.15	1.76	1.43	0.97	4.76
2001	0.48	0.14	1.87	1.55	1.03	5.07
2002	0.56	0.18	2.17	1.80	1.27	5.98
2003	0.68	0.09	2.79	2.22	1.50	7.29
2004	0.78	0.08	3.37	2.55	1.73	8.51
2005	0.93	0.18	4.02	3.11	1.42	9.65
2006	1.99	0.44	5.92	9.50	3.07	20.93
2007	2.13	0.54	6.78	11.71	4.25	25.40
2008	2.16	0.60	8.43	13.24	3.81	28.25
2009	1.76	0.76	8.07	12.49	4.75	27.84
2010	2.06	1.27	9.03	15.51	7.93	35.80
2011	2.53	2.16	9.31	18.04	10.72	42.75
2012	2.34	1.99	9.13	19.64	11.78	44.87
2013	7.28	1.86	12.80	25.50	17.83	65.25
2014	6.04	1.73	10.73	20.50	16.50	55.50
2015	5.48	1.17	9.87	20.02	3.68	40.22
2016	6.08	0.69	11.71	24.66	7.18	50.31
2017	6.13	1.08	11.82	26.27	4.32	49.62
2018	6.81	1.16	12.21	29.40	4.03	53.60
2019	6.94	1.40	11.84	30.85	3.45	54.48
2020	7.67	1.57	13.21	31.65	4.76	58.85

	RESIDENTIAL FEC (TJ)				
i=1	final energy consumed from biomass				
i=2	final energy consumed by electricity				
i=3	final energy consumed from clean fuels				
	YEAR	FECr, bio	FECr, ele	FECcf	FEC, r (TJ)
		i=1	i=2	i=3	
	2000	127,402	5,699	4,185	137,287
	2001	120,563	7,697	5,499	133,759
	2002	114,362	5,940	4,250	124,552
	2003	108,853	6,790	4,581	120,224
	2004	104,101	7,243	5,044	116,388
	2005	98,866	7,150	5,081	111,097
	2006	94,411	7,578	6,070	108,060
	2007	91,248	7,542	5,822	104,612
	2008	88,562	8,168	5,625	102,355
	2009	86,866	8,712	10,203	105,781
	2010	86,014	8,939	8,562	103,514
	2011	91,285	15,944	8,155	115,384
	2012	91,811	17,586	8,905	118,302
	2013	94,333	18,907	7,778	121,018
	2014	95,769	18,990	6,746	121,505
	2015	96,063	18,175	7,619	121,857
	2016	95,717	18,771	7,751	122,240
	2017	98,808	20,517	8,826	128,151
	2018	100,461	24,758	9,191	134,410
	2019	97,877	25,084	9,519	132,479
	2020	99,305	27,955	10,614	137,874

RESIDENTIAL ACTIVITY				
i=1	Population with access to electricity			
i=2	The population that uses traditional biomass			
i=3	Population with access to clean fuels			
	POPele, access	POPbio	POPcf	TOTAL POP
	i=1	i=2	i=3	
2000	8,593,824	11,071,678	1,219,261	19,665,502
2001	9,055,143	11,140,434	1,332,908	20,195,577
2002	9,721,323	11,037,003	1,494,599	20,758,326
2003	10,302,155	11,027,359	1,685,032	21,329,514
2004	11,133,020	10,773,424	1,862,048	21,906,444
2005	9,279,992	13,216,959	2,137,210	22,496,951
2006	12,725,808	10,372,778	2,425,352	23,098,586
2007	13,492,504	10,215,816	2,797,582	23,708,320
2008	14,717,283	9,608,804	3,162,391	24,326,087
2009	15,234,599	9,716,163	3,617,860	24,950,762
2010	16,418,970	9,155,749	4,091,955	25,574,719
2011	16,788,197	9,417,744	4,533,628	26,205,941
2012	15,177,886	11,680,876	5,022,588	26,858,762
2013	19,460,597	8,065,000	5,395,017	27,525,597
2014	22,077,748	6,118,610	5,780,253	28,196,358
2015	21,364,572	7,506,367	6,091,768	28,870,939
2016	23,436,562	6,117,741	6,442,838	29,554,303
2017	23,875,587	6,346,675	6,618,675	30,222,262
2018	24,819,995	6,050,646	6,853,282	30,870,641
2019	26,321,112	5,201,178	7,060,993	31,522,290
2020	27,495,117	4,685,284	7,144,049	32,180,401

PRIMARY AND FINAL ENERGY CONSUMPTION

	PEC	FEC
2000	265,360	248,601
2001	265,537	239,647
2002	261,021	235,248
2003	252,509	213,990
2004	248,144	211,473
2005	240,541	211,325
2006	270,174	216,587
2007	268,961	212,433
2008	267,356	207,683
2009	252,272	240,331
2010	286,716	244,516
2011	318,674	279,523
2012	351,781	304,756
2013	356,188	306,364
2014	371,930	309,335
2015	386,976	312,070
2016	376,259	309,116
2017	362,563	309,771
2018	425,278	335,983
2019	443,624	347,343
2020	490,228	368,303