Master of Science

Emergy-Based Assessment of Ghana's Socioeconomic Metabolism

The Graduate School
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Emergy-Based Assessment of Ghana’s Socioeconomic Metabolism

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DEDICATION

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ABSTRACT

Ghana epitomizes as one of the fastest-growing Sub-Saharan African economies, attributable to increases in the pricing of its export commodities and increased resource extraction. While its natural resource rents as percentage of GDP have more than doubled during the same period, the underlying question is how long can this macroeconomic momentum and poverty reduction, anchored firmly on natural resources, be sustained? This work assessed Ghana's socioeconomic sustainability from 2000, 2010 to 2019 based on emergy synthesis. Emergy Synthesis (ES) is an ecological accounting technique that allows energy, material, labor, and currency flows to be directly compared using a common unit of measure. Additionally, the study investigated the effect of urbanization on Ghana's socioeconomic metabolism. The Emergy Synthesis indicated that total emergy use increased by 126% from 2000 to 2019. The change in total emergy use was attributable to increased import emergy, from 2.90% to 37.47% while Ghana's self-sufficiency capacity decreased from 97.10% to 62.53% in the investigated period. This variation in total emergy utilization categorizes the Ghanaian socioeconomic system as transitioning from high dependence on indigenous resources to a growing reliance on purchased resources to drive economic growth. Emergy use per person (EC) indicated approximately 18% drop in the amount of geobiosphere resources invested in each person in 2019 compared to 2000. The decline in EC does not necessarily depict a drop in living standards due to rapid intensification in economic and industrial activities observed in the investigated period. The observed decrease in Emergy Yield Ratio (EYR) and increase in Emergy Investment Ratio (EIR) suggests that the country benefits more from its trading partners. The increasing environmental loading ratio (ELR) trend signals rising environmental stress imposed by purchased resources Emergy sustainability index (EmSI) value of Ghana is less than 1, categorizing Ghana's socioeconomic system as resource-consuming and low-environmental performance. The study recommends restructuring Ghana's socioeconomic system to ensure optimal use of its indigenous renewable resources to the largest possible extent while minimizing its nonrenewable resources and import dependency. Additionally, the increasing urban area partly drives resource consumption, particularly refined fuels and construction materials, highlighting the necessity for urban policies that appreciate changes in socioeconomic metabolism as a framework of reference for urban land administration.

Keywords: emergy synthesis; emergy indicators; socioeconomic metabolism; Ghana

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CHAPTER I

INTRODUCTION

The evolution of human societies cannot be fully comprehended without considering the immense supportive role of the natural environment. Energy and material resource are extracted from the natural environment and used as resource inputs for production and consumption processes to drive human societies' functioning mechanisms, after which waste and other products are emitted back to the natural environment; this describes the metabolism of human societies. The energy and material flow from the surrounding natural environment and fossil energies from external environment are the principal sources of power for human societies (Huang & Chen, 2005); consequently, human societies' sustainability depends on the continuous inflows provided by the natural environment. Several approaches have been used to evaluate the interactive relationships between human societies and the support provided by the natural environment and the sustainability of human societies. One of the best applicable theories is socioeconomic metabolism theory. Socioeconomic metabolism is an adaptation of the metabolism theory, allowing us to understand the interrelations of resource exchange between human societies and natural environment. From the perspective of socioeconomic metabolism, human societies can be understood as open systems that act as a hub for energy and material resource convergence from their domestic environment or purchased from external economies. These open systems transform the resources in an economic process not only to drive their functioning mechanisms but provide goods and services which remains in the socioeconomic system in the form of society's assets; thus, residential buildings, industries, transport infrastructure, public infrastructure, and population (Schandl & Schulz, 2002).

Urbanization has led to enormous pressure on the ecological environment in exploiting resources to meet human needs. Even though urbanization is a crucial driver of economic growth, the process of urbanization increases society's metabolic rate, resulting in large-scale resource consumption, loss of farmlands and forested areas, increased extraction of construction materials, traffic congestion, and an increase in emissions, all of which affect the balance of economic growth and environmental quality. Technological innovations in resource extraction have consequently led to increasing fluxes of energy and materials, altering the interrelations between human societies and the natural environment. Therefore, human societies face two challenges; inevitable resource depletion on the input side and increasing resource consumption rates on the output side (Schandl & Schulz, 2002). The question raised here is, "how can our human societies anchored firmly on the natural environment, be sustainable?" It is imperative to analyze the interactive relations between human societies and the natural environment to undertake purposive interventions to reduce society's activities on resource extraction and adjust societal and economic growth to natural conditions to achieve sustainable development.

Socioeconomic metabolism approaches include; Material-flow accounting (MFA), Ecological footprint, Ecological network analysis (ENA), and Emergy synthesis (ES). To better harness the full potential and immense supportive role of the natural environment to human societies, socioeconomic metabolism methodologies must account for the embodied free environment work and quality of resources. However, due to the difficulties of comparing resources in the same unit, most socioeconomic metabolism methodologies ignore the free environment work embodied in resource flows (Huang & Chen, 2009). Among the methodologies of socioeconomic metabolism, Howard T. Odum's Emergy Synthesis (ES) considers the free environmental work required for energy and material resource generation and the quality of energy consumed when assessing systems' environmental performance. Emergy Synthesis is based on the rationale that all resource flows are generated from solar energy. Therefore, it allows the conversion of energy, material, human services, currency, and information flows into solar emergy equivalents (Odum, 1996), making them directly comparable. Emergy synthesis can inform several policies and decision-making to maximize the utilization of available resources in production processes, increase economic development and sustainability of systems (Ascione et al., 2009; Hossaini et al., 2013; Rutebuka et al., 2018). This study used emergy synthesis approach as the socioeconomic metabolism assessment of Ghana is performed from an environmental performance and sustainability perspective.

In emergy synthesis, a set of performance indicators are aggregated to measure and capture the trend of environmental support to a system, stress imposed on the environment, well-being of a population, gains, and losses in foreign trade, intensity of industrial and economic activities, and the overall sustainability of a system. This study used nine (9) relevant emergy performance indices to assess the environmental performance of Ghana's socioeconomic system which comprise; emergy use per person (EC), empower density (ED), emergy self-sufficiency ratio (ESR), emergy to money ratio (EMR), emergy exchange ratio (EER), emergy yield ratio (EYR), environmental loading ratio (ELR), emergy sustainability index (EmSI), and the renewable carrying capacity (R%). Detailed explanation of the emergy performance indicators are presented in (Chapter III).

Ghana's macroeconomic growth has accelerated in recent decades, attributable to increases in the pricing of its export commodities and increased resource extraction. Consequently, Ghana's GDP growth and GDP per capita has more than quadrupled since 1995 and was designated a Lower-Middle Income Country in 2011. While natural resource rents as a percentage of GDP have more than doubled during the same period, the underlying question is how long can this macroeconomic momentum and poverty reduction, anchored firmly on natural resources, be sustained? Is Ghana benefiting from high prices of export commodities or overexploiting its indigenous non-renewable resources? Currently, Ghana remains one of the countries that epitomize the rapid urbanization occurring on the African continent. (GSS, 2021) reports that between 2010 and 2021, Ghana's urban population increased by 39.3 %, while the rural population grew by 10.3 %. Furthermore, the urban population is estimated to reach 65% by 2030. (Farvacque-Vitkovic et al., 2008; Owusu & Oteng-Ababio, 2015). Concomitant to the speed and scale of urbanization is the substantial changes to the country's landscape and demography which primarily affect the support provided by the natural environment. Therefore, it is imperative to understand the trend and sustainability status of Ghana's socioeconomic metabolism to serve as a framework of reference for present and future policymaking. This assessment will also contribute to literature on emergy-based assessment of African socioeconomic metabolism.

1.1 Research Questions

These questions form the core of the study;

1. How long can Ghana's macroeconomic momentum and poverty reduction, anchored firmly on natural resources, be sustained?
2. Is Ghana over-exploiting its indigenous non-renewable resources?
3. What effect does urbanization have on Ghana's metabolism?

1.2 Research Objectives

Considering the urgency to evaluate the sustainability of Ghana's socioeconomic metabolism;

1. The thrust of the study is to perform resources consumption assessment of Ghana from 2000 to 2019 based on emergy synthesis.
2. The second theme of inquiry is; relevant emergy-based indices are calculated to measure Ghana's sustainability level, highlighting the extent to which the Ghanaian socioeconomic metabolism fulfills the conditions for sustainable development.
3. The third theme of inquiry is to investigate the effect of urbanization on Ghana's socioeconomic metabolism. This aim will also help contribute to current literature on changing land-use patterns in urban Ghana.

1.3 Scope of Study

This work traced the dynamism of major renewable and nonrenewable resources flow supporting the socioeconomic system of Ghana from 2000 to 2019 using emergy synthesis. Three-time periods in the last two decades were selected to assess Ghana's socioeconomic metabolism before and after the nation transitioned to a Lower Middle-Income status in 2011. Due to data inconsistencies of Ghana's material, energy, and resource flows, the study period is restricted to 2000, 2010, and 2019. The time periods were determined by access to national and international statistical reports.

1.4 Rationale of Study

Ghana's economic momentum is firmly anchored on its natural resource base while overexploiting natural resources, rendering its economic growth and development susceptible to potential shocks. Given the speed and scale of the country's urbanization, this trend of overexploitation of natural resources is expected to worsen over the next several decades. The threat to Ghana's economic growth posed by the inevitable depletion of its natural resource base has not been fully comprehended as several economic assessments and indicators fail to account for the embodied free environmental work necessary for resource generation. Emergy synthesis of Ghana's socioeconomic system will allow measuring various types of economic and environmental work in the same units, assisting policy revision and the formulation of environmentally-conscious policies to use natural resources sustainably for societal benefits. Understanding the pattern of Ghana's emergy flows and land use changes would also serve as a reference framework for present and future urban land administration. Furthermore, emergy application to African socioeconomic systems is still in the infant stages. This study offers insights and suggestions for policy revision and the design of new policies for other Sub-Saharan African nations with similar characteristics to Ghana.

1.5 Thesis Organization

This study is structured into six chapters, of which Chapter I comprise the introduction, research objectives, scope, and rationale of the study. Chapter II discusses the literature that shapes the core of the study. It includes a detailed review of socioeconomic metabolism theory, land use and socioeconomic metabolism, methodological approaches of socioeconomic metabolism, emergy synthesis, and its applications. Chapter III is in two major parts. The first part describes Ghana. Under this, the geographic location of Ghana is defined. Other details such as the demographics, social and economic characteristics of Ghana are discussed as well as land use trends. The second part of the chapter is the methodology. It includes a detailed review of emergy synthesis and its accounting procedures, emergy-based performance indicators selected, and the data sources. Chapter IV embodies the results and discussions of emergy synthesis of Ghana’s socioeconomic system while Chapter V investigates the effect of urbanization on Ghana's socioeconomic metabolism. Chapter VI presents the conclusion and practical policy suggestions derived from the results and findings of this study.

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CHAPTER II

LITERATURE REVIEW

2.0 Introduction

Chapter II discusses socioeconomic metabolism and its methodological approaches. Firstly, socioeconomic metabolism is discussed to provide a clear perspective of the energy and material resource exchange between human societies and the surrounding natural environment. Secondly, interrelations between land use and socioeconomic metabolism are explored. Finally, Emergy Synthesis methodology and its application on different scales are discussed. The review of the related literature gives insight and background knowledge related to the research topic.

2.1 Socioeconomic Metabolism; Human Societies and the Natural Environment

The evolution and growth of human societies are inextricably linked to energy, and material resource flows generated from the natural environment. World Bank (WB, 2020), reports that about seven out of ten persons will reside in urban centers by 2050. Urbanization increases the rate of resource consumption which causes irreparable changes in the natural environment, consequently affecting the free biophysical support provided by nature. Presently, the high rates of resource extraction and consumption necessitate the need to account for the free biophysical support sustaining human societies. Taking the concept of socioeconomic metabolism as a reference point to understand and coordinate the relationship between human societies and their surrounding environment is imperative in understanding how human societies persist and a paramount approach toward sustainable development.

According to Fischer-Kowalski and Haberl (1997); Huang et al. (2006), "societal metabolism and colonization" are the two fundamental concepts that can be used to understand the interactive relations between human societies and nature. From the biological perspective, metabolism is the physical processes in living organisms that define the energy cycle associated with the conversion of matter, necessary for reproduction and survival of living organisms (Schandl & Schulz, 2002). Metabolism has been a central theory and adopted in various fields of study to coordinate relations between organisms and nature The core assumption of socioeconomic metabolism is that human societies are analogous to organisms that require materials and energy resource from nature to sustain life-supporting and functioning mechanisms (Fischer-Kowalski & Haberl, 1998; Schandl & Schulz, 2002; Huang et al., 2006; Ingold, 2008; Dunn, 2016). From the perspective of socioeconomic metabolism, human societies must sustain permanent throughput of energy and matter that is at least equivalent to the entire metabolism of its population as a condition for survival; furthermore, human societies must purposefully manage resource throughput to be in balance with natural conditions (Schandl & Schulz, 2002; Huang et al., 2006).

Human societies are conceived of here as open systems whose existence and maintenance rely on fluxes of energy and materials from their surrounding environments and whose growth is constrained by the finite natural environment. The flows of resource exchange accumulate and transform the morphology of the natural environment, and land use change helps track and analyze the human influence on the natural environment.

2.2 Land Use and Socioeconomic Metabolism

Human societies deliberately modify the natural environment to provide material components to sustain their needs, causing a change in the morphology of our natural ecosystems. Consequently, land use change is a key indicator to capture and track the trends of socioeconomic metabolism. Fischer-Kowalski and Haberl (1997), Fischer-Kowalski and Weisz, (1999), Haberl et al. (2001a), Krausmann et al. (2003) conceptualizes land use as ‘’colonization of terrestrial ecosystems’’. Thus, human societies invest energy or work to alter the natural ecosystem into a colonized terrestrial ecosystem that induces structural changes in the natural ecosystem for services provision. A typical example is the conversion of wetlands into infrastructure to deliver services for human use. “Colonization of terrestrial ecosystems” can be assessed through two fundamental approaches; “(1) by describing the socio-economic activities that intervene into ecosystems in order to get the desired results, and (2) by describing the changes in ecosystem processes resulting from these interventions Krausmann et al. (2003). Urbanization is causing an intensification of resource consumption by human societies which is adversely affecting the functioning of the natural environment. The "colonization of terrestrial ecosystems" poses ramifications not just for the natural environment but the sustainability of human societies. Therefore, it is critical to investigate the effect human-induced land use changes on socioeconomic metabolism and vice versa; how changes in socioeconomic metabolism cause land use change.

Research on socioeconomic metabolism and land use change has been employed at different scales; Krausmann et al. (2003) investigated the relations between changes in land cover and socioeconomic metabolism of Austria. The study revealed that industrialization in Austria alters land use for society's metabolism. Huang et al. (2006) analyzed the relations between land use and socioeconomic metabolism in Taiwan. The findings showed that land use patterns directly affect the socioeconomic metabolism. This work investigates urbanization effect on the socioeconomic metabolism of Ghana. The aim is to add more information on how the urbanization of Ghana affects the consumption of indigenous non-renewable resources and purchased inputs.

2.3 Methodological Approaches of Socioeconomic Metabolism Analyses

Socioeconomic metabolism incorporates interdisciplinary theories and perspectives from ecology, biology, physical geography, economics, and sociology fields. The concept of socioeconomic metabolism has been utilized to analyze cities through material and nutrient flows; (Faerge et al., 2001; Barret et al., 2002; Obernosterer, 2002; Burstrom et al., 2003; Gandy, 2004; Schulz, 2007; Niza et al., 2009; Thériault & Laroche, 2009; Kennedy et al., 2011; Barragán-Escandón et al., 2017). Among the studies of socioeconomic metabolism, the methodologies that have been widely employed in the analyses resource exchange between human society and natural environment include;

2.3.1 Material Flow Accounting (MFA)

Material Flow Accounting (MFA) quantifies ways in which material flows to the human society are transformed, reused, and discharged (Graedel, 2019). In MFA, the total amount of material inputs must correspond to total output, including storage and stock changes within the system. The limitation of MFA is the difficulty of connecting weight-based indicators to environmental impact evaluations (Hinterberger et al., 2003; Vega Azamar, 2013). Studies that have utilized MFA methodology include; (Decker et al., 2000; Hendriks et al., 2000; Browne et al., 2011; Rosado et al., 2014;).

2.3.2 Ecological Footprint (EF)

Ecological Footprint quantifies the amount of earth's regenerative capacity (or bio capacity) demanded by given activity (Wackernagel et al., 2019). In other words, EF expresses the quantity of land and (water) required to create resources and the capacity to absorb the waste generated. Some researchers have used ecological Footprint to conduct socioeconomic analyses including; (Folke, C., & Kautsky, N. 2000; Muniz & Galindo, 2005; Moore et al., 2013).

2.3.3 Ecological Network Analysis (ENA)

Ecological Network Analysis (ENA) identifies system components that may be undetected by direct observations (Faith et al. 2007). The ecological network analysis (ENA) is widely used to characterize sustainability of urban systems, food webs, habitat fragmentation, and so forth. Studies that have applied ecological network analysis methodology for socioeconomic metabolism include (Zhang et al., 2014; Chen & Chen 2015).

2.3.4 Emergy Synthesis (ES)

Emergy Synthesis (ES) is a resource accounting approach that considers the free environmental work and non-marketed ecosystem services required to generate energy and material resource and the quality of energy consumed when assessing systems' environmental performance. Emergy Synthesis is based on the rationale that all resource flows are generated from solar energy. Therefore, it allows for converting different material and resource flows into solar emergy equivalents, making them directly comparable. Studies that have applied emergy synthesis methodology for socioeconomic metabolism at various scales include; (Zucchetto, 1975; Stanhill, 1977; Odum, 1983; Huang, 1998; Sciubba & Ulgiati, 2005; Sciubba et al., 2008; Huang et al., 2006; Huang & Chen, 2009; Zhang, 2012). Resource exchange between human societies and the natural environment advances beyond the resource flows to support and sustain human societies. Aggregating resource flows based on their mass neglects the free environmental work that generated the resources (Huang et al., 2006). Indeed, emergy synthesis is the most comprehensive resource accounting methodology that accounts for the free environmental work in energy, material, and resource generation from its origin to present state.

2.4 Emergy Synthesis: A Common Input Accounting For Natural Environment and Economies

Howard T. Odum's Emergy Synthesis (ES) integrates energy quality and hierarchy to evaluate the supportive role or worth of different energy and material resource flows consumed in a system, a product, or service. Emergy synthesis provides the most comprehensive assessment of a system's dynamics, allowing resource flows from the natural environment, economic, and social storage to be directly comparable. Emergy (spelled with "m") refers to the sum of available energy (exergy) of one form or another that is required directly and indirectly to generate a product or service, measures in units of solar equivalent joules (seJ)(Odum, 1996). Emergy tracks the embodied energies invested in a resource from its origin to present state (Odum, 1996). Emergy accounts for renewable, non-renewable resources, imported /purchased resources, finished / manufactured goods, information, technology, human services on a common unit as solar emjoules (Odum, 1996; Santagata et al., 2020). Emergy regards solar energy as the standard unit of measurement as almost all processes in the biosphere, resource formation and energy flows are generated from the sun Through transformation coefficients, non-solar source flows are converted into a unified value- i.e. solar emjoules (Odum, 1996; Ascione et al., 2009). In this regard, the unit of emergy (previous energy used) is solar emergy joules (sej).

Generally, macroeconomic indicators fail to account for the environmental dimension or non-marketed ecosystem services in analyzing the performance of human-influenced systems. This exclusion of the environmental dimension has created a gap, resulting in ecologically unfriendly policies (Lei et al., 2012; Rutebuka et al., 2016). However, the emergy approach regards natural environment and human societies as interconnected systems. This principle allows for the most comprehensive assessment of the human societies' sustainability to make environmentally-conscious decisions.

2.4.1 Concept of Self-Organization and Maximum Empower Principle

Self-organization concept in emergy synthesis is critical in understanding the environmental performance of a system. Self-organized systems optimally utilize their indigenous renewable resources, assuring long-term survival. Self-organizing systems have the propensity to utilize energy efficiently and prevail against other systems in competition for energy and material resources, ensuring their long-term sustainability. Rydberg and Haden (2006) indicated that the concept of self-organization provides insight into systems' capacity to harness emergy flows to generate new organizational states within a given time. Self-organizing systems are driven by maximum empower. Brown and Ulgiati (1999) explain the maximum empower principle as "systems that self-organize and prevail against competition develop the most useful work with inflowing energy sources by reinforcing productive processes and overcoming limitations through system organization" (p. 488). In this context, a system will be sustainable in the long term if it utilizes more energy sources efficiently and feedback control that reinforces energy flows to power the system. Rydberg and Haden (2006) opined that the long-term survival of a system will immensely depend on an internal organization that efficiently utilizes renewable sources. Therefore, as the criterion for sustainability, Ghana's sustainability will immensely depend on modifying its socioeconomic system to optimally utilize indigenous renewable emergy sources while reducing reliance on nonrenewable emergy sources.

2.5 Application of Emergy Synthesis Methodology in Socioeconomic Metabolism and Sustainability Studies

On the urban and regional ecosystem scale, Mellino et al. (2014) combined geographic information system (GIS) and emergy synthesis to assess the sustainability of Italy's Campania Region. The findings identified locations of primary indigenous renewable emergy flows to promote sustainable use of land and resources. Vega-Azamar et al. (2015) applied emergy synthesis to evaluate the sustainability of residential land use type in Montreal. Huang et al. (2015) applied emergy synthesis to investigate the effect of land use on urban metabolism.

On the national scale, emergy synthesis have been applied to; France (Pasquier, 1999) Sweden (Hagström & Nilsson, 2004), Spain (Lomas et al., 2008), Brazil and Italy (Pereira et al., 2010), Brazil (Giannetti et al., 2013), Japan (Gasparatos & Gadda, 2009). Studies presented and reviewed below are some of the time series emergy synthesis of different countries;

Huang and Odum (1991) identified that Taiwan's ecological-economic status shifted from rural to industrialize due to manufacturing and export merchandise, resulting in rapid economic growth from 1960 to 1990. Yang et al. (2010) conducted a comprehensive assessment of the Chinese economy from 1978 to 2005 using the ecological measure of solar emergy and synthesizing various kinds of resource flows.

Lomas et al. (2008) highlighted that Spain is declining in self-sufficiency and less efficient in resource use using a historical series of resource flows from 1984 to 2002. The findings further revealed that the Spanish economy is significantly driven by import emergy and tourist emergy flows.

Lei et al. (2008) analyzed emergy trend of Macao using historical series of resource flows from 1983 to 2003 and performed a simulation to estimate future emergy trends for the next twenty years. The findings revealed drastic increase in total emergy use, environmental loading ratio, and low sustainability performance. The simulation results indicated that total emergy use and environmental loading ratio of Macao would increase sharply in the future.

Gasparatos and Gadda (2009) described the resource consumption of Japanese society from 1979 to 2003 using emergy synthesis. The findings showed that total emergy use increased by 66% while environmental stress increased by 93.7% with growing reliance on import emergy largely from developing nations.

Oliveira et al. (2012) analyzed the Portuguese economy using resource flows from 2000 to 2009. The findings revealed a low system performance in exploiting and transforming emergy from purchased inputs and traded at a disadvantage (loss of real wealth) in the global market within the study period.

Lei and Zhou (2012) analyzed national economies of 102 countries evaluating the per capita emergy trends using the data from National Environmental Accounting Database. The results signaled that majority of national economies are resource-consuming significantly reducing the overall global long-term sustainability.

Lou and Ulgiati (2013) described the evolution of the Chinese economy from 1978 to 2009 using the emergy accounting method. The results revealed that total emergy use of the Chinese economy increased by 5.6 times, associated with a declining emergy sustainability index (ESI) trend signaling that the Chinese economic development imposes significant ecosystem stress and unsustainable in the long term.

Li and Brown (2017) identified that Mongolia traded in emergy loss in foreign trade from 1995 to 2012. The findings indicated that total emergy use (U) increased by 75% with a declining emergy purchasing power in the study period. The Emergy Exchange Ratio (EER) indicated that Mongolia exported more than 3.3 times emergy than emergy received in international trade. The study concluded that the Mongolian economy is increasingly susceptible to global market shocks due to increasing dependence on imported emergy and a drastic increase in exports.

Giannetti et al. (2013) conducted an environmental performance assessment of Brazil compared to Russia, India, China, South Africa, and the United States. The findings revealed that large GDP economies depend immensely on developing economies to support and sustain the former, consequently impeding the latter's development.

González-Mejía and MA (2017) assessed Puerto Rico's sustainability using historical series of emergy flows 1960 to 2013. The findings characterized Puerto Rico as a resource-consuming system and rely immensely on external resources from its trading partners, particularly the United States. Finally, Yang et al. (2020) concluded that renewable resource fractions in total emery steadily declined in three island countries (Malaysia, Indonesia and Philippines) from 2000 to 2015.

Despite the growing literature on emergy synthesis application to systems, there is a research gap on emergy application to African socioeconomic systems. Only one African country has undertaken a comprehensive study of its economic development utilizing emergy synthesis at the time of this paper (Rutebuka et al., 2016). The sustainability of Ghana's economic growth threatened by the inevitable depletion of its indigenous nonrenewable resource base has not been holistically comprehended due to the inadequacy of economic indicators and other resource accounting tools to account for the environmental work used up in energy and material resource generation. Furthermore, given that the rate and extent of Ghana's urbanization have a substantial impact on resource consumption and the country's landscape, it is critical to investigate the effect of urbanization on the metabolism of socioeconomic systems. Therefore, the questions conceived hereof are; How long can Ghana's macroeconomic momentum and poverty reduction, anchored firmly on natural resources, be sustained? Is Ghana over-exploiting its indigenous non-renewable resources? What effect does urbanization have on Ghana's metabolism? This research utilized emergy resource accounting to analyze the trend of Ghana's metabolism and sustainability.

Emergy synthesis will emphasize the principal resource base driving Ghana's economic growth and long-term sustainability. Understanding the trend of Ghana's emergy flows will provide historical context on economic development and insights for policy revision and formulation. The findings of this work will contribute to the literature on the evolution of African socioeconomic systems.

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CHAPTER III

STUDY AREA, DATA AND METHODOLOGY

3.0 Introduction

Ghana's macroeconomic growth is firmly anchored on its natural resources, whereas the rapid expansion of its urban areas alters the interactive relations between its integrated ecological-economic systems, making it more challenging to enforce sustainability principles. Natural resource contribution to GDP is decreasing as a result of diversification and progressive transformation from an agrarian to a services-led economy. Even though the services sector currently dominates Ghana's GDP, the country's natural resource base remains critical to its economic development. The threat of inevitable depletion of the natural resource base has not been fully comprehended. Therefore, this work seeks to track and capture the trend of resources supporting the Ghanaian economy, overall environmental performance, and long-term sustainability. This study incorporates Emergy Synthesis (ES) to evaluate Ghana's socioeconomic system using resource flows from 2000 to 2019. This chapter presents an overview of Ghana's demographics, social and economic growth, land use trends, data and collection sources, and the methodology.

3.1 Profile of Ghana

Ghana is located in West Africa and covers 238,535km^2. Ghana has a population of about 31,072,945 people (GSS, 2021). The average daily temperatures range from 25 to 35^{o} C with a relative humidity of 77% to 85%. Ghana has a tropical climate with annual rainfall averaging 2000millimeters in the southwestern part and decreasing to 1000millimeters in the north. Vegetation cover includes closed-canopy forests mangrove and savannah formations. Ghana is subdivided into ten (16) administrative regions, and six (6) metropolitan areas, with Accra functioning as the administrative and political capital (Figure 1). Ghana attained independence from British colonial rule in 1957. Between 1966 and 1981, Ghana's economic growth and development were thwarted by successive coup d'états. However, the promulgation of the 1992 constitution by the Fourth Republic has resulted in Ghana being a much more stable and democratic state since then. Table I provides a summary of the general facts about Ghana.

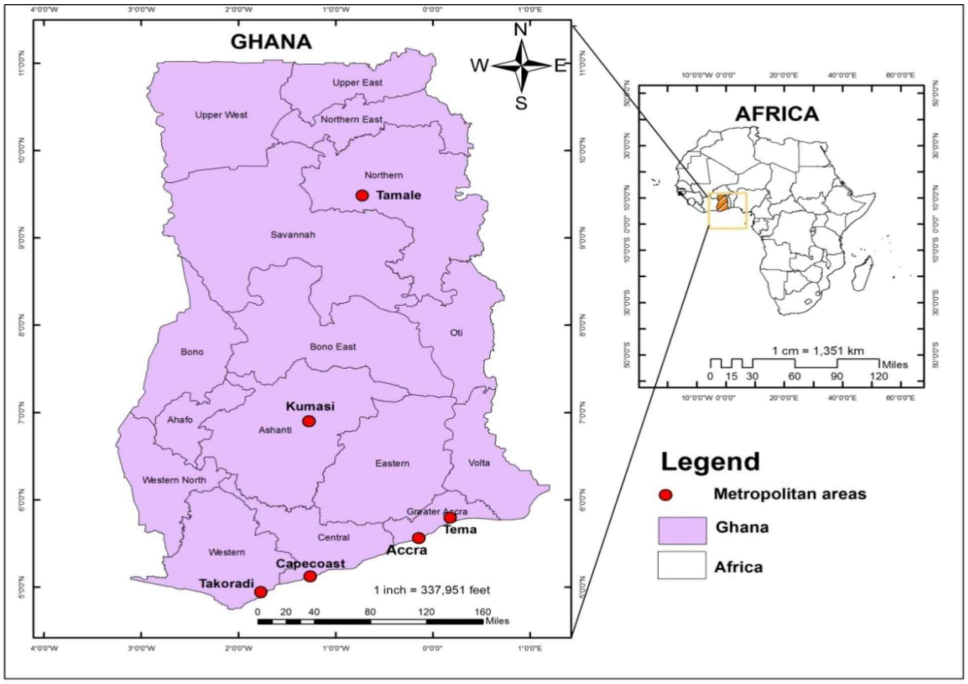


Figure . The location of Ghana.

TABLE 1 General facts about Ghana.

Land	
Total Land area(sq. km)	**238,535**
Population	
Population, 2021	**31,072,945.0**
Population growth rate %, 2021	**2.12**
Urban Population,2021	**17,472,530.0**
Urban Population growth rate, % 2020	**3.31**
Land area of Built-up/urban areas, 2019 sq. km	**3,098.55**
Rural Population, 2021	**13,539,489.0**
Population density (people per sq. km of land area),2021	**130.0**
Life expectancy at birth, total (years),2019	**64.1**
Economic Conditions	
GDP growth (annual %), 2019	**6.5**
GDP per capita growth (annual %)	**4.2**
GDP per capita, 2019USD	**2,210.36**

Unemployment,(% of total labor force) 2020	**4.53**
Foreign Direct Investment(FDI),2019USD	**3,879,831,469.7**
Social Conditions	
Adult (+15) literacy rate (%),2018	**79.04**
Adult literacy rate male(%),2018	**83.52**
Adult literacy rate female (%), 2018	**74.47**

Source: Ghana Statistical Service, GSS (2000-2021)

3.2 Brief Description of Ghana's Socioeconomic Development

Ghana is one of Africa's fastest-growing economies, and its diverse variety of mineral deposits and cash crops has made it a target for foreign investment. Ghana is Africa's second-largest exporter of gold and the first largest cocoa exporter; the revenue obtained from these exports cannot be underestimated. Ghana sits on multiple mineral deposits: gold, diamond, bauxite, manganese, steel, aluminum, oil, natural gas, and among others. Prior to crude oil exploitation and production in 2010, gold accounted for 90-95% of mineral exports Gold exports accounted for USD$ 10billion while crude oil accounted for USD$ 4.65 billion (OEC 2021).

Despite the immense contribution of agriculture and mineral extractive industries to Ghana's GDP growth, the country is gradually transitioning from an agricultural to a services-led economy. The share of the services sector to GDP has increased significantly due to tourism growth and favorable government policies in the banking and insurance sector, which have attracted local and international investment into the economy. Furthermore, budgetary adjustments that preserve social and priority expenditure, the restoration of external buffers, and the maintenance of banking sector stability are central to government economic policy (The Report: Ghana 2020, 2020).

This has resulted in increased trust and investor confidence in the Ghanaian economy According to the study by Ato-Mensah and Long (2021) on the expansion of the Ghanaian employment market, more than 80% of newly generated jobs between 2008 and 2018 resulted from government initiatives and foreign direct investment (FDI) in Ghana. Most FDIs are concentrated in critical industries such as manufacturing, general trade, and construction, providing numerous job possibilities for skilled and semi-skilled workers. Between 2005 and 2010, the services sector's share of GDP grew from 28.91 % to 48.18 %, while the agriculture sector's share of GDP declined from 37.45 % to 28.04 %. As of 2019, the service sector accounted for 45.14 % of GDP, while agriculture accounted for 17.32 % (Figure 2). Concomitant to the impressive GDP growth, GDP per capita has more than quadrupled since 1995, while the population has increased by 78.78% over the same period (Figure 3). Ghana's economic performance in 2019 resulted in a GDP per capita of USD224.63, higher than the sub-Saharan average of USD1, 484.

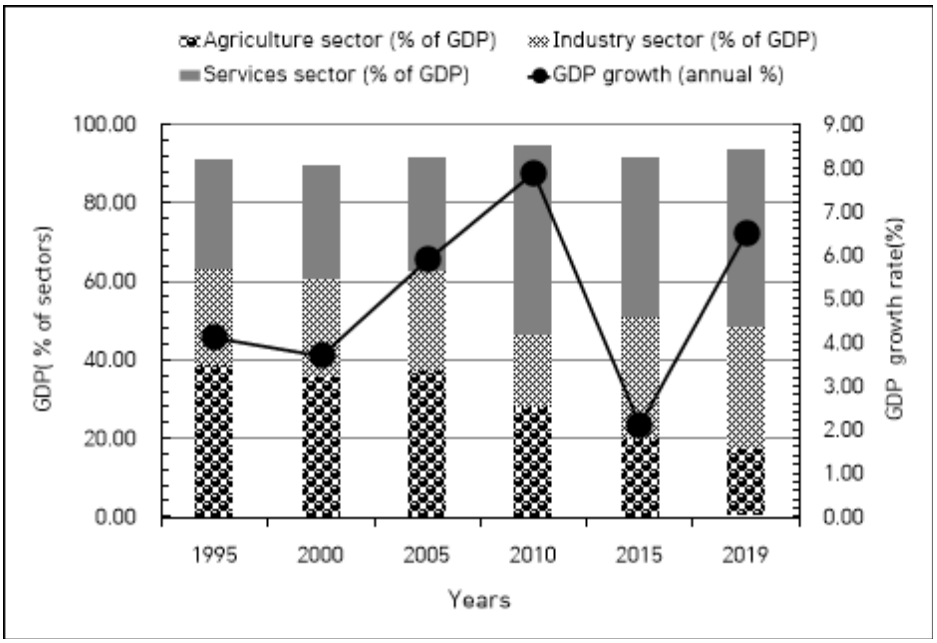


Figure 2. Economic development of Ghana from 1995 to 2019.

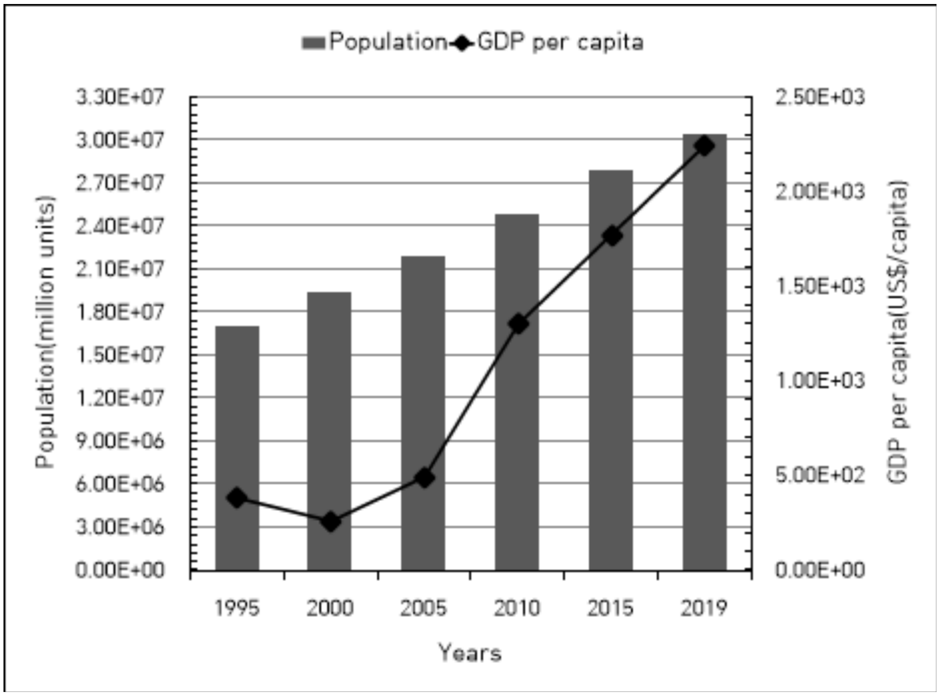


Figure 3. Trend of GDP per capita and Population of Ghana from 1995 to 2019.

Even though Ghana's minerals and crude oil are exported in their unprocessed state, the revenue obtained by the country is paramount to economic growth, with GDP more than quadrupling in recent years. However, one notable trend is that natural resource rents as a percentage of GDP have declined since 2010. Forest and mineral rents percentage of GDP show a downward trend from 2005 and 2010 respectively (Figure 4). Meanwhile, the percentage of oil and natural gas rents of GDP has steadily risen due to government initiatives and foreign direct investments (FDIs) in the oil and gas industry. Furthermore, cocoa bean exports totaled USD 1.161 billion in 2019, propelling economic growth and export performance. Ghana's Non-Traditional Exports (NTE) increased from USD2.813billion in 2018 to USD2.899billion in 2019. NTE growth is linked to improved performance of processed and semi-processed products, notably cocoa butter, palm oil, iron, and steel products (Ghana Export Promotion Authority [GEPA] NTE REPORT, 2020).

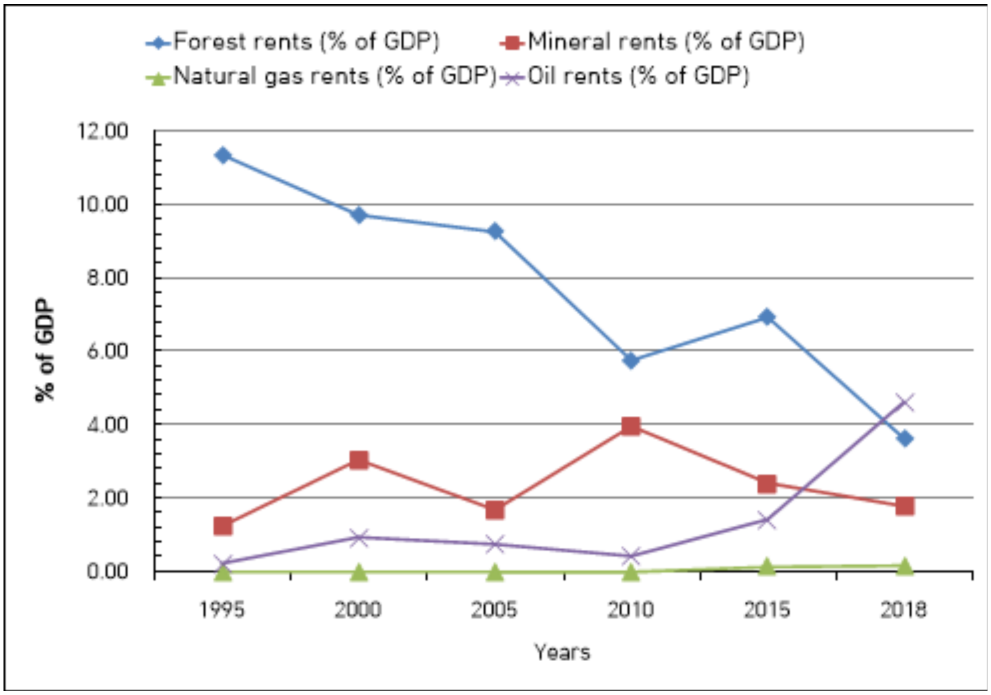


Figure 4. Natural resource rents as % of GDP from 1995 to 2019.

Ghana’s economic growth in recent decades has resulted urbanization and increased resource consumption rates. Consecutive census reports in Ghana reveal that the urban population increased from 50% to 56.7% between 2010 and 2021, with almost half (47.8%) of the increase concentrated in major urban centers such as Accra, Kumasi, Tema, CapeCoast Takoradi, and Tamale (GSS 2021). In 2021, Greater Accra Region, Ghana's national capital, recorded an urban population of 91.7% (GSS, 2021). This speed and scale of Ghana's urban growth and development are attributed several causes including; the natural increase of population, net in-migration to urban areas, enhanced economic development, increased Foreign Direct Investment (FDI) and foreign startups; consequently altering land use in Ghana. The next section of the chapter discusses urbanization and trend of land use and land cover change in Ghana.

3.3 Urbanization and Land Use Change in Ghana

Urbanization has dominated social, economic, and environmental sustainability discourses in recent years. The heightened interest is against the backdrop that urban areas generate 80% of the world's GDP and consume 70-75% of total natural resources (Tan et al., 2021), making it more challenging to enforce the principles of sustainability within such areas. Ghana's economic growth has resulted in increased urbanization and high resource consumption. Expansion of urban areas alters the interactive relations between the integrated ecological-economic systems and causes irreparable changes in the long term. Today, nearly 56.7% of Ghana's population lives in urban areas and will surpass 70% by 2050 The increase in the urbanization rate in Ghana has been the need for people to access opportunities available in urban areas and the increased commercialization and industrialization in urban centers. In Ghana, there is a rising social acceptance that urban life is of respectable antiquity, driving people to relocate from the countryside to urban areas. Furthermore, government policy guarantees that more resources are directed to urban areas making them more developed than rural areas. As a result, the majority of the populace is drawn to urban areas because they have more amenities and jobs.

Land-use and Land-cover change (LULCC) analyses were carried out using data acquired from European Space Agency (ESA) for the study period, i.e., 2000, 2010, and 2019. The LULCC years were selected to correspond with the period for emergy evaluation of Ghana's socioeconomic system. Land cover data for 2000 is considered as a baseline. Land cover was classified into Agriculture, Bare Land, Built-up/Urban areas, Undeveloped Forest, and Waterbody (see Table 1.1). Figure 5 shows the areal and percentage LULCC from 2000 to 2019. Ghana's 2000, 2010, and 2019 land use and land cover maps are shown in Figure 6.

3.3.1 Expansion of Built Up Areas

Built-up areas currently account for 1.30% of Ghana's total land area which amounts to 3,098.55sqkm^2 of as 2019. In general, built-up areas expanded by 139.32%, gaining approximately 1,803.80sqkm^2 with the highest increase of 59.58% was recorded between 2010 and 2019 (Figure 5). The expansion in built-up areas occurred mainly in the southern part of Ghana, which harbors five metropolitan areas namely; Accra, Kumasi, Tema, Cape Coast and Sekondi Takoradi. Substantial gains observed within the metropolitan areas are related to microeconomic policies, rural-urban migration, foreign direct investment, and aid, as well as activities of extractive industries (Attua & Fisher, 2011; Achemapong et al., 2018; Addae & Oppelt, 2019; Ampim et al., 2021). This expansion was due to a significant amount of agricultural land (659.89 sqkm^2) being converted to other land cover types, predominantly built-up areas, between 2010 and 2019. Recent research findings, Naab et al. (2013), Amoateng et al. (2013), Yeboah et al. (2017), Ashiabgor et al. (2019) indicated that decrease in agricultural land cover to built-up areas is primarily due to urbanization, especially in peri-urban areas. Agyemang et al. (2019) found that the spatial structure of urban Ghana is increasingly becoming deconcentrated, dispersive, and amorphous. Ghana's urbanization has been dominantly characterized with lateral developments (low-rise buildings) sprawling away from the urban centers to the peri-urban areas. This is evidenced by the increase in built-up areas, particularly after 2010, from 1294.74km^2 in 2000 to 3098.54km^2 in 2019. The increase in lateral developments is primarily influenced by the decentralization initiative and the establishment of new growth nodes away from the urban centers, which are prioritized by the planning authorities.

Table 1.1 Land use of Ghana: 2000 to 2019

Land use type	2000	2010	2019
Agriculture, km^2	112078.6196	112963.265	112303.3718
(%)	46.88%	47.25%	46.97%
Bare land km^2	41209.08369	33438.53444	78.09626153
(%)	17.24%	13.99%	0.03%
Built-up, km^2	1294.744027	1941.689545	3098.544998
(%)	0.54%	0.81%	1.30%
Undeveloped Forest areas, km^2	77697.43645	83907.58268	116451.0661
(%)	32.50%	35.10%	48.71%
Water body, km^2	6792.169729	6820.981836	7140.974302
(%)	2.84%	2.85%	2.99%
Total Land Area km^2	**239,072.05**	**239,072.05**	**239,072.05**

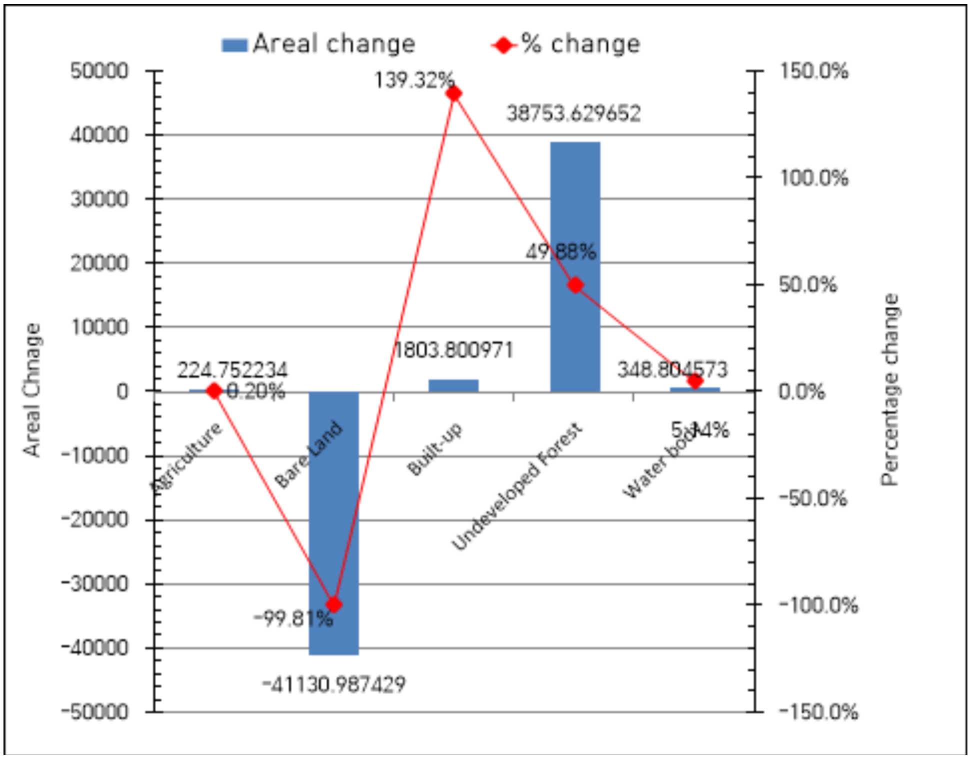


Figure 5. Areal & percentage land cover change from 2000 to 2019.

3.3.2 Fluctuating increase in Agricultural and Undeveloped Forested lands

The loss in agricultural land in 2019 did not translate into a decline of primary staple food production, as production of main staple food remained the same or slightly increased. Ampim P.A. et al. (2021) study reported that most of the increment in agricultural land between 2000 and 2010 occurred in the Northern regions of Ghana, which corresponds with the observation made in this LULCC analysis. Currently, agricultural land account for 46.97% (see Table 1.1) and primarily provides staple food and cash crops, fruits and vegetables, poultry, and livestock production.

Throughout the analyses, undeveloped forested areas increased by (38,753.63sqkm^2) and averaged approximately 38.77%. An indication from the LULCC map was the conversion of bare land to undeveloped forested areas predominantly in the northern part of Ghana between 2010 and 2019. The increment in undeveloped forested areas is partially due to governmental and non-governmental organizations' initiatives such as the Afforestation and Re-afforestation Programmes to replenish the dwindling timber reserves in the country.

3.3.3 Loss of Bare land areas and increase in water bodies

Bare land areas decreased significantly throughout the study time frame. The most losses of this land-use cover type were recorded between 2010 and 2019, accounting for approximately 33,360sq.km^2.The loss of bare land areas correlates with increased built-up and undeveloped forested areas within the same timeframe (see fig. 1). Addae and Oppelt (2019) reports that reduction in bare land areas is often due to urban development, which corresponds to the observation made in this study. Water bodies increased throughout the research period, averaging 2.89 %, with the highest increase of 320km^2 occurring between 2010 and 2019. The observed increments in this land cover type are due to several factors; amount of rainfall and other climatic conditions.

Ghana’s macroeconomic growth is firmly anchored on its natural resources whereas the speed and scale of urbanization alter land cover and land use and potentially affect the functioning and life-supporting mechanisms of the country’s socioeconomic system. Therefore, it is urgent to investigate the interrelations between changes in Ghana’s socioeconomic metabolism and the growth of the urban areas to inform policy decisions. This study utilizes emergy synthesis (ES) to assess energy, and material resource flow supporting Ghana's socioeconomic system from 2000 to 2019.

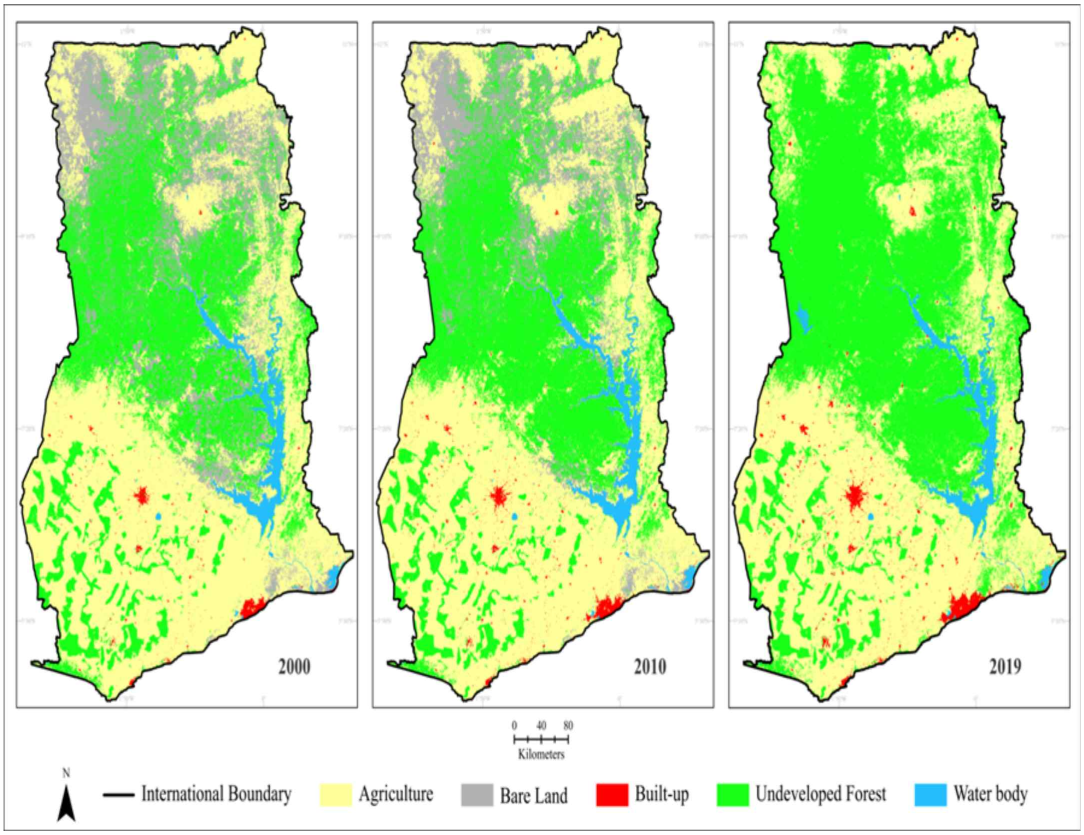


Figure 6. Land use and Land cover maps of Ghana 2000 to 2019.

3.4 Data Sources and Collection

Due to data inconsistencies of Ghana's material, energy, and resource flows, the study period is restricted to 2000, 2010, and 2019. Three-time periods in the last two decades were selected to assess Ghana's socioeconomic metabolism before and after the nation transitioned to a Lower Middle-Income status in 2011. The time periods were determined by access to national and international statistical reports. Specifically, data on food and cash crops, livestock, fishery, timber, and other agricultural products were obtained from United Nations Food and Agriculture Organization datasets, Ghana Ministry of Food and Agriculture Ghana Forestry Commission and Ministry of Land and Natural Resources annual reports. Fossil fuels, biomass (wood and charcoal), and electricity data were obtained from Ghana Energy Commission Reports 2000, 2010, and 2019.

Minerals and metals production data were obtained from the Ghana Chamber of Mines Annual Reports (2000-2019) while data on imports, exports and other international trade statistics were collected from Bank of Ghana database, world development indicators (WDI), United Nations Commodity and Trade database, World Integrated Trade Solution database and Resource Trade Earth database (RTE, 2000-2019). Tourism is included in the exported services emergy flow since international inbound visitors consume goods, artifacts, and hospitality services, notwithstanding tourism expenditure by local citizens. Data on tourism was obtained from the Bank of Ghana database. Data on Ghana's demographics were cited from Ghana Statistical Service Reports (2010-2019). Data for the calculations of sunlight hours, wind energy, rainfall, tidal energy, and geothermal potential were obtained from literature and Wikipedia.

In order to carry out a systematic comparison of Ghana's emergy performance indicators with other countries, published emergy indicators of some selected countries were sampled from; Hagström et al., (2004), Jiang et al., (2008), Pereira et al., (2010), Oliveira et al., (2012), Hossaini et al., (2013), Giannetti et al., (2013), González-Mejía & Ma, (2017), Rutebuka E., et al., (2018) and Yang et al., (2020).

3.5 Methodology

3.5.1 Emergy Synthesis (ES)

The interactive relations between human societies and the natural environment can be fully comprehended by Howard T. Odum's concept of energy hierarchy applicable to all systems. Emergy (spelled with "m") refers to the sum of available energy (exergy) of one form or another that is required directly and indirectly to generate a product or service, measures in units of solar equivalent Joules (seJ)(Odum, 1996). Total emergy (U), is the sum of the emergy of all input flows used up in resource, service or product generation. The total emergy is calculated by multiplying all raw resource inflows by the appropriate Unit Emergy Values (UEV) (Santagata et al., 2020). According to Odum (1996), different forms of energy have different energy qualities, and the ability to do work varies. Typical is the quality of energy generated by fossil energies (natural gas, crude oil, coal), often higher than renewables (solar, wind, etc.). Higher quality energy is often associated with high concentration, making it more flexible for different uses. Emergy Synthesis considers the quality differences of energy used in work or resource formation by record of cumulative energy quality, making it more comprehensive than other resource accounting techniques.

3.5.2 Unit Emergy Values (UEVs)

Unit Emergy Values (UEVs) refers to the amount of solar emergy needed, directly or indirectly to generate one unit of a product or service (Odum, 1996). Thus, the input emergy captured and consumed per unit output flow or product (M. Ascione et al, 2009). The higher the UEV, the more embodied energies consumed to generate it (Brown et al., 2004; Hossaini et al., 2013). Equation for total emergy is shown below;

$$[\ U_x = \sum_i (Tr\ .Ex)\ ]$$

U_x represents the total emergy associated to an *xth* product, *Ex* denotes the available energy (exergy) of the *xth* input, *Tr* as transformity defined as: $Tr = U_x / Ex$ (Odum 1996; Mellino et al. 2014). UEV is expressed in solar equivalents as sej/J, sej/g, and sej/$ (Odum, 2000). UEVs are divided into two categories: "Transformity" and "Specific emergy".

3.5.2.1 Transformity and Specific Emergy

Transformities are UEVs that are quantified in joules (J). Transformity denoted as emergy input/emergy output. Transformity helps us to relate all forms of energy qualities to one form of energy and quantifies the embodied energies consumed and used up in a product generation. The units of transformity are emjoules per joule (seJ) (Odum, 2000). Specific emergy is the unit emergy value of matter, mass or money. The specific emergy value of mass is expressed in (seJ/g), and the emergy per monetary unit is expressed in (seJ/$) (Srinivasan & Moe, 2015).

Unit emergy values (UEVs) ensure the accuracy of emergy-based assessment and must correlate to the quantity of solar radiation driving the geobiosphere, also known as the Global emergy baseline (GEB). The Global emergy has been revised multiple times due to variations in solar radiation or changes in the earth's orbit. Before 2000, several emergy-based analyses employed the total emergy baseline of 9.44E+24seJ/yr proposed by Odum (1996). To account for gravitational and geothermal sources, Odum (2000) revised the geobiosphere emergy baseline to 15.83E+24seJ/yr. The geobiosphere emergy baseline was recently recalculated as 12.0E+24seJ/yr (Brown & Ulgiati, 2016). This research drew on 12.0E+24seJ/yr emergy baseline, and as such, all other UEVs from literature were converted accordingly.

3.5.3 Energy Systems Diagram

In emergy synthesis, an emergy systems diagram of the product, service or system under consideration is drawn to arrange the system's components and evaluate all inputs and outflows (Brown et al., 2000). Understanding the system, its boundaries, and surroundings is paramount in emergy synthesis. Defining the system boundary helps simplify the interactions within the system's components and its inputs and outputs exchanges with their surroundings. Given that the socioeconomic systems are open systems, conceptualizing the system boundary, the resource inflows and transformation inside the system, and the output flows are paramount. The energy systems diagram is illustrated by a common set of symbols called (ESL) Energy Systems Language developed by Odum (1996). The energy systems symbols have characteristic meaning and semantic rules that communicate the structure and interactions within the systems and its surroundings. Figure 7 shows the procedure undertaken to conduct an emergy evaluation of a system under consideration are;

(1) Define the system's primary energy and material resource flows. Using the energy system symbols, design a detailed system diagram that shows the resource input and output flows, storage, and assets;

(2) Raw data (exergy) of the input and output flows are collected to calculate the corresponding emergy flow by multiplying the exergy by the appropriate UEVs;

(3) Calculation of emergy-based performance indices for final interpretation.

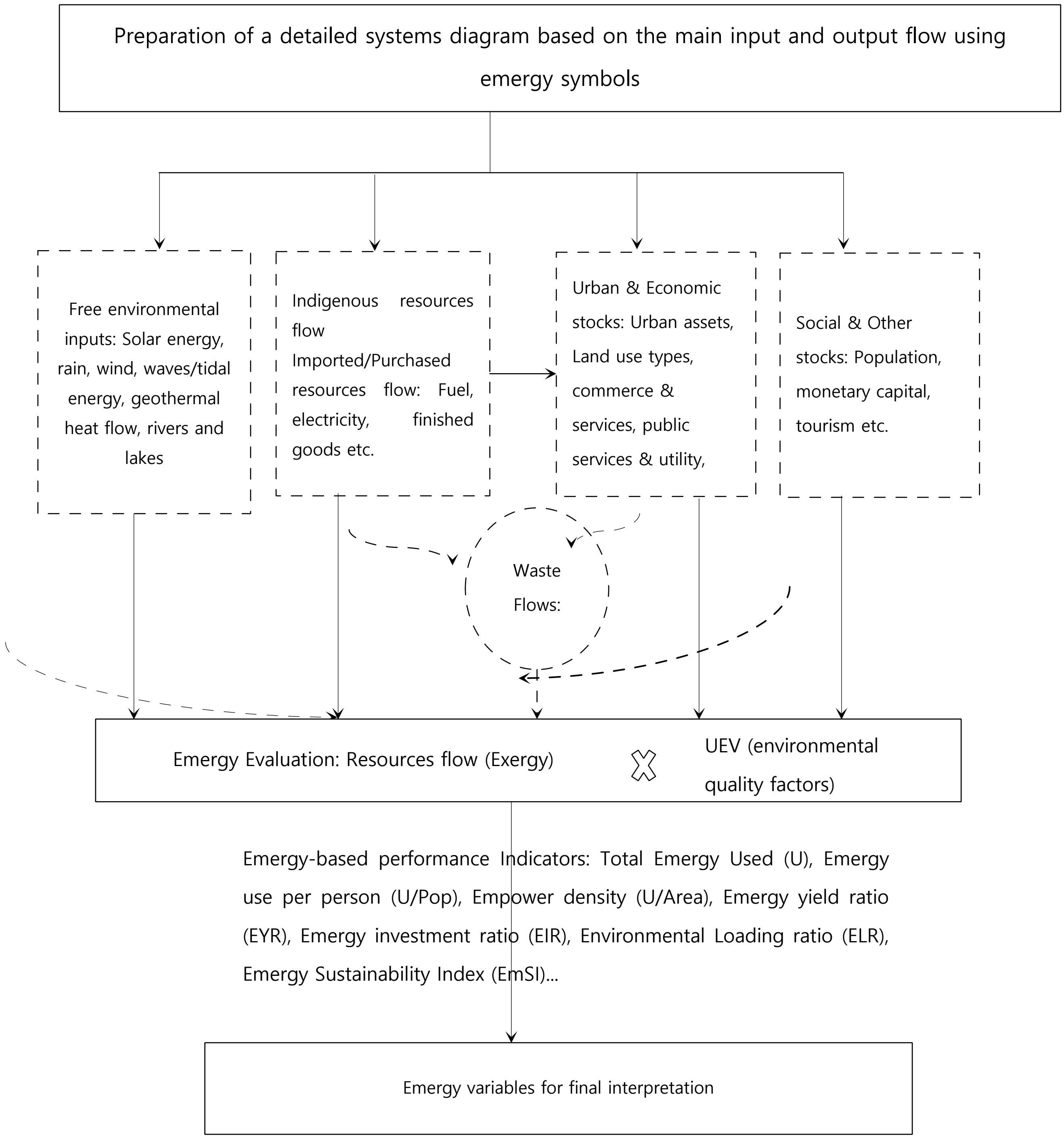


Figure 7. Procedure adopted for Emergy assessment of Ghana's ecological-economic system

3.5.4 Evaluation Indicators: Emergy-based Performance Indicators

Using the emergy accounting procedure and aggregated emergy flows, performance indicators suitable for environmentally-conscious decisions and policymaking can be calculated. The emergy indicators are discussed within the context of the social-economic-natural compound indicator framework as published by several papers (Oliveira et al. 2012; Yang et al. 2020). Generally, social indices measure the population's standard of living and intensity of resources utilized within the system, whereas economic indices evaluate the gains and losses in external exchange. Finally, natural indices measure the degree of stress and pollution on the natural environment. The emergy-based performance indicators calculated and interpreted are elaborated in (Table 2);

Table 2: Emergy-based performance indicators

Indicators	Description	Expression
Social indicators		
Emergy use per person (EC)	EC measures the real standard of living of a population (Campbell & Ohrt, 2009). The higher the EC index, the higher the quality of life and well-being of the population.	Total emergy(U)/Population
Empower density (ED)	ED quantifies total emergy use/land area in a given time. The higher the ED index, the larger the production efficiency and the more the economy become developed.	U/land area
Emergy Self-sufficiency ratio (ESR)	ESR measures indigenous emergy sources/ total emergy use. This indicator measures the degree of intensity of indigenous resources use within the system.	(R+N)/U
Economic indicators		
Emergy money ratio(EMR)	EMR quantifies the amount of real wealth purchased with money within a given period (Odum, 1996).	U/GDP
Emergy exchange ratio (EER)	(EER) denoted as export emergy/import emergy and measures the gains and losses of a system in foreign trade (Wang et al., 2021).	Export emergy /import emergy
Emergy Yield Ratio (EYR)	EYR measures the ability of a system to exploit and make available local resources by investing outside resources (Ascione et al., 2009).	U/[F+G+P21]
Natural indicators		
Environmental loading ratio (ELR)	ELR is the quotient of indigenous non-renewable emergy flows (N) and import emergy (F+G+P21) divided by locally renewable emergy flows (R) and quantifies the degree of stress and pollution in the natural environment.	[N+F+G+P21]/R
Emergy Sustainability Index (EmSI)	EmSI measures the sustainability of a system. A system is considered sustainable if it obtains a high yield ratio at lower environmental stress.	EYR/ELR
Renewable Carrying Capacity	Renewable carrying capacity is the ratio renewable resource emergy/ total emergy use multiplied by the system's population. This index assesses the capacity of renewable resources to support a system's population at current living standards (Campbell & Ohrt 2009).	R/U*Population

3.6 Emergy Synthesis of Ghana's Socioeconomic Metabolism

Figure 8 shows Ghana's socioeconomic system using energy systems symbols. Figure 9 is the legend for the energy systems symbols used. Renewable energies are represented on the left-side of the diagram, comprising sun, wind, waves/tidal energy, rain, and geothermal energy, the primary natural energies sources that support Ghana's socioeconomic system.

Nonrenewable resource flows (N), including fossil fuels, electricity, food, finished goods and machinery, construction materials, and imported services, are represented on the upper-side. Nonrenewable resources (N) are resources whose reserves are exploited quicker than replenished. Locally available nonrenewable resources (N) are classified as dispersed rural resources (N_0), concentrated resources (N_1), and nonrenewable exported resources (N_2) (Jiang et al., 2008). Dispersed rural resources (N_0) comprise topsoil loss, forest extraction, fishery production, and water extraction. N_1 and N_2 represent metals, minerals, and fuel reserves, formed and replenished over extended geological periods (Jiang et al. 2008; Rutebuka et al. 2016). The right-side, including tourism, government, and external markets, is the output. Detailed information about the energy systems symbols can be found in (Odum, 1996). The emergy system diagram guarantees the ability to assess Ghana's environmental performance, self-sufficiency, and sustainability from 2000, 2010, and 2019.

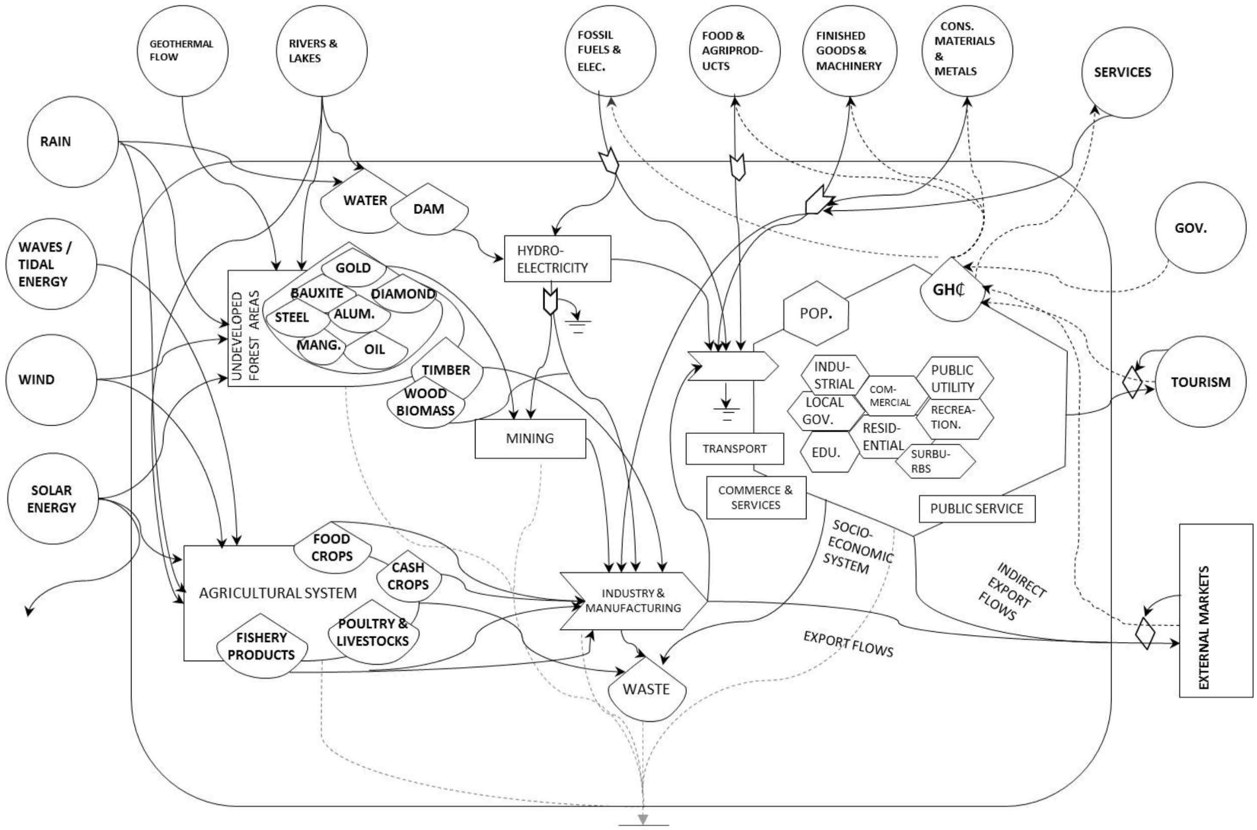


Figure 8. Conceptual energy diagram of Ghana's Socioeconomic system.

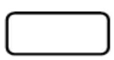
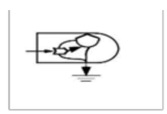
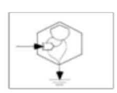
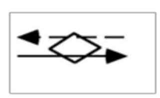
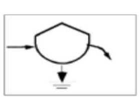
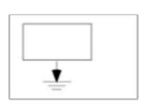
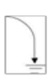
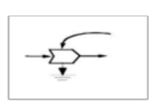
	*System frame: A rectangular box drawn to represent the boundaries of the system under consideration.*		*Producer: These include units that collect and transform low-quality energy under control interactions of higher quality flows.*
	*Pathway line: A pathway whose flow is proportional to the quantity in the storage or upstream source.*		*Consumer: Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.*
	*Source: Flow-limited energy or resource input; energy, material, services and information flows.*		*Exchange Transaction:* A unit that indicates the sale of goods or services (solid line) in exchange for payment of money (dashed line).
	*Storage: A compartment of energy storage within the system storing quantity as the balance of inflows and outflows; a state variable.*		*Box:* A miscellaneous symbol used for any subsystem structure or function.
	*Heat sink: Dispersion of potential energy into heat that accompanies all real transformation processes and storages;*		*Interaction: process which combines different types of energy flows or material flows to produce and outflow in proportion to a function of the inflows.*

Figure 9. Energy systems symbols and description. Adapted from Odum (1996).

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CHAPTER IV

RESULTS AND DISCUSSION

4.1 Introduction

Chapter IV undertakes an emergy synthesis of the major resources flows supporting the Ghanaian socioeconomic system, generating relevant emergy performance indicators to evaluate the environmental performance and highlight the extent to which the Ghanaian socioeconomic metabolism fulfills the conditions for sustainable development. The interpretation and detailed discussion of the emergy-based performance indicators provides a clear perspective and understanding of Ghana's economic growth and actual living standards to inform policy decisions. The Emergy Synthesis revealed a shift in Total emergy use (U) growth behavior with a growing dependency on import emergy. Import emergy/total emergy use increased from 2.90% to 37.47%, while Ghana's self-sufficiency capacity decreased from 97.10% to 62.53% in the study period. This variation in total emergy use is partly attributed to Ghana's progressive diversification of its economy and rising import demand driven by multilateral trade agreements in the form of tariff reductions and removal. The 18% drop in emergy use per person (EC) does not necessarily depict a drop in living standards due to significant rise in economic and industrial activities (reflected by the Empower indicator) observed in the investigated period. ESI trend suggests that suggests that Ghana is moving further away from being in equilibrium with its natural environment, necessitating industrial strengthening and upgrading to reduce dependency for purchased inputs.

Table 3 consolidate the main emergy flows and Table 4 provides a summary of performance indicators used to assess Ghana’s socioeconomic system from 2000, 2010, to 2019. Each input in Table 3 is classified into one of the following categories based on its nature; renewable resources, indigenous renewable energy, indigenous non-renewable sources flow within Ghana, imports, and exports. This work used the 12.0E+24 seJ/yr emergy baseline published by (Brown et al., 2016). Hence, the UEVs used were updated to the emergy baseline accordingly. Table 4 summarizes the emergy performance indicators used to assess the emergy intensities of Ghana’s socioeconomic system. Tables 5 compare Ghana's emergy-based performance indicators to those of 25 other countries from literature to assess Ghana's ecological and resource utilization status. The Appendix comprises detailed calculation procedures of each resource input in Table 3 and references for the data on each resource input.

Table 3 Emergy evaluation table of resource flows in Ghana from 2000, 2010 and 2019.

Note	Resource Item	2000	2010	2019	Transformity (sej/unit)	Source of published value of transformity
		Solar emergy flows, sej/yr				
Renewable resources(R)						
1	Solar radiation	2.50E+22	2.50E+22	2.50E+22	1.00E+00	Odum et al. (2000), folio 1
2	Wind, Kinetic energy	4.97E+20	4.97E+20	4.97E+20	2.45E+03	Odum et al. (2000), folio 1
3	Rain, chemical energy	1.62E+22	1.70E+22	1.65E+22	3.05E+04	Odum et al. (2000), folio 1
4	Rain, geo potential energy	4.78E+21	4.84E+21	4.67E+21	4.70E+04	Odum et al. (2000), folio 1
5	Deep heat	1.49E+21	1.49E+21	1.48E+21	4.90E+03	Brown & Ulgiati 2016
6	Tidal energy	1.73E+22	1.73E+22	1.73E+22	7.39E+04	Odum et al. (2000), folio 1
7	Waves	0.00E+00	0.00E+00	0.00E+00	5.10E+04	Odum et al. (2000), folio 1
Indigenous Renewable energy(sej/yr)						
8	Hydroelectricity	6.92E+21	7.36E+21	7.80E+21	2.92E+05	Odum, 1996
9	Main food crops excluding Cash crops	5.85E+18	9.52E+18	1.53E+19	4.27E+05	Odum,1996
10	Cash crops	9.91E+17	1.65E+18	8.24E+17	4.27E+05	Odum,1996
11	Fruits and vegetables	3.87E+21	7.07E+21	2.21E+21	1.28E+09	Odum, 1996
12	Cereals and derivatives	1.04E+21	1.76E+21	2.55E+21	6.04E+08	Odum, 1996
13	Poultry and Livestock	5.41E+22	8.40E+22	9.40E+22	3.36E+06	Brown,2004
14	Fisheries	3.17E+22	2.46E+22	3.23E+22	3.36E+06	Brown, 2004
15	Biomass Production	3.43E+21	2.84E+21	3.72E+21	5.86E+04	Cohen et al., 2006
16	Timber harvest	2.82E+21	3.95E+21	1.50E+19	1.66E+04	Brown et al., 2000
Locally available non-renewable source flow; Dispersal use (N_0)						
17	Topsoil loss	7.54E+20	7.54E+20	7.54E+20	2.25E+05	Odum,1996
Non-renewable source flow within Ghana: Concentrated Use (N_1)						
18	Gold	3.52E+16	4.51E+16	6.97E+16	5.36E+08	Odum, 1996 p.114
19	Diamond	2.66E+14	1.31E+14	1.44E+13	2.13E+09	Odum, 1996
20	Bauxite	5.49E+20	5.58E+20	1.22E+21	1.09E+09	Odum, 1996 p.187
21	Manganese	1.07E+21	2.02E+21	9.79E+21	1.68E+09	Odum 1996
22	Aluminum	1.21E+20	3.06E+18	3.35E+19	7.76E+08	Bargigli, 2004
23	Steel	0.00E+00	5.65E+19	5.65E+19	2.26E+09	Odum, 1996 p.186
24	Natural gas	0.00E+00	0.00E+00	3.80E+19	6.10E+04	Odum, 1996
25	Crude Oil	0.00E+00	0.00E+00	2.79E+22	6.73E+04	Odum 1996, p.186
Imports						
26	LPG(Liquid Petroleum Gas	1.33E+19	5.50E+19	1.02E+20	8.89E+04	Odum,1996
27	Gasoline	2.27E+20	3.36E+20	7.41E+20	1.40E+05	Brown et al., 2011
28	Gas oil	1.98E+20	4.73E+20	9.48E+20	1.30E+05	Brown et al., 2011
29	ATK	0.00E+00	0.00E+00	1.04E+20	1.38E+05	Brown et al., 2011
30	Electricity	7.03E+20	8.63E+19	1.03E+20	2.26E+05	Odum et al.,1996 p .305
31	Aluminum	2.94E+18	1.99E+19	3.10E+19	7.76E+08	Bargigli, 2004
32	Steel	5.99E+19	1.34E+20	1.74E+20	2.26E+09	Odum, 1996 p.186
33	Copper	1.90E+20	1.64E+20	4.95E+20	8.64E+10	Odum et al., 2000
34	Zinc	3.82E+19	5.34E+18	6.40E+18	8.64E+10	Odum et al.,2000
35	Fertilizers & Pesticides	1.18E+17	8.54E+17	8.35E+17	2.36E+06	Odum, 1996
36	Plastic and Synthetic Rubber	4.50E+20	7.70E+20	1.66E+21	5.46E+09	Odum,1996
37	Chemicals	1.40E+17	3.71E+17	4.56E+17	4.38E+04	Odum, 1996
38	Machinery and transport equip.	2.18E+16	8.39E+16	9.62E+16	8.51E+09	Odum,1996
39	Construction materials	2.35E+21	3.90E+21	9.68E+21	2.70E+09	Buranakarn V., 1998.
40	Textiles	4.15E+16	6.76E+16	5.12E+16	4.83E+06	Odum 1996

41	Glass	2.78E+19	5.56E+19	5.83E+19	1.07E+09	Odum 1996
42	Food and Agric. Products	4.17E+17	8.45E+17	1.38E+18	4.27E+05	Odum,1996
43	Livestock & Fishery	3.29E+13	2.74E+13	7.69E+17	3.36E+06	Brown,2004
44	Service for imports	7.18E+20	3.69E+21	1.32E+23	1.23E+12	Cialani et al. 2005
Exports						
45	Food and Agric. Products	2.25E+17	2.63E+17	8.45E+17	4.27E+05	Brown, 2004
46	Livestock, meat, fish	8.74E+11	1.31E+11	2.35E+17	3.36E+06	Brown,2004
47	Liquid Petroleum Gas(LPG)	2.31E+18	0.00E+00	2.98E+17	8.89E+04	Odum,1996
48	Gasoline	0.00E+00	5.80E+18	1.95E+19	1.40E+05	Brown et al., 2011
49	Gasoil	3.26E+17	1.59E+20	6.38E+19	1.30E+05	Brown et al., 2011
50	Heavy Gasoline	6.49E+19	5.53E+19	4.43E+19	1.41E+05	Odum 1996
51	ATK	5.45E+19	5.95E+19	1.20E+20	1.38E+05	Brown et al., 2011
52	Aluminum	9.39E+19	2.70E+19	4.34E+19	7.76E+08	Bargigli, 2004
53	Steel	1.63E+19	5.90E+18	4.02E+19	2.26E+09	Odum, 1996
54	Gold	3.52E+16	4.51E+16	7.13E+16	5.36E+08	Odum, 1996
55	Diamond	2.66E+14	1.31E+14	1.44E+13	2.13E+09	Odum, 1996
56	Bauxite	3.27E+20	5.45E+20	1.20E+21	1.09E+09	Odum, 1996
57	Manganese	1.01E+21	1.85E+21	9.24E+21	1.68E+09	Odum 1996
58	Timber	4.02E+19	5.48E+19	3.00E+19	1.66E+04	Brown, 2000
59	Cash crops	2.25E+17	2.24E+17	5.85E+17	4.27E+05	Odum 1996
60	Fertilizers	1.50E+15	2.69E+16	1.43E+16	2.36E+06	Odum 1996
61	Plastic	9.88E+17	2.35E+19	5.26E+18	5.46E+09	Odum 1996
62	Textiles	2.08E+15	3.08E+15	2.56E+14	4.83E+06	Odum 1996
63	Paper and derivatives	3.19E+13	4.16E+13	4.81E+14	1.80E+05	Buranakan V. 1998
64	Electricity	3.19E+20	8.43E+20	1.16E+21	2.26E+05	Odum,1996 p .305
65	Chemicals	4.95E+11	3.61E+13	3.06E+13	4.38E+04	Odum 1996
66	Service in exports (tourism included)	2.13E+21	6.25E+21	3.69E+22	4.22E+12	Hossaini et al., 2013
Waste						
67	Solid waste	3.61E+24	4.67E+24	5.68E+24	1.61E+12	Buranakan V. 1998
68	Construction waste	3.08E+24	3.94E+24	4.86E+24	4.56E+12	Buranakan V. 1998
Specific Sectors						
69	Expenditure on Gov. support (health, education, salaries)	3.87E+20	3.83E+21	7.97E+21	1.23E+12	Cialani et al. 2005

UEVs refer to 12.0E+24 seJ/yr emergy baseline

Table 4 Emergy performance indicators of Ghana from 2000, 2010, and 2019.

Index	Description	Units	2000	2010	2019
R	Renewable resources flow	sej/yr	6.52E+22	6.61E+22	6.55E+22
N	Indigenous non-renewable emergy flow (N_0+N_1)	sej/yr	1.01E+23	1.26E+23	1.78E+23
N0	Dispersed Non-renewable production	sej/yr	9.28E+22	1.16E+23	1.31E+23
N1	Concentrated Non-renewable production	sej/yr	8.66E+21	9.99E+21	4.68E+22
N2	Non-renewable flows exported without use(mineral and metals direct export)	sej/yr	1.57E+21	2.71E+21	1.08E+22
F	Imported fuel, metals and mineral imports	sej/yr	7.29E+20	1.19E+21	2.60E+21
G	Goods and Electricity Imports	sej/yr	3.53E+21	4.81E+21	1.15E+22
P21	Emergy value of services in imports (Item 44)	$/year	7.18E+20	3.69E+21	1.32E+23
U	Total emergy used (R+N0+N1+F+G+P21)	sej/yr	1.72E+23	2.02E+23	3.89E+23
IME	Total imported emergy (F+G+P21)	sej/yr	4.98E+21	9.69E+21	1.46E+23
G'	Emergy flow of goods and electricity exports	sej/yr	3.60E+20	9.22E+20	1.20E+21
P1E	Emergy value of services in exports(item 69)	sej/yr	2.13E+21	6.25E+21	3.69E+22
E	Total exported emergy (G'+N2+P1E)	sej/yr	4.05E+21	9.87E+21	4.89E+22
IME-E	Imports minus exports ([F+G+P21]-[G'+N2+P1E]	sej/yr	9.23E+20	-1.81E+20	9.68E+22
EER	Exports to imports ([G'+N2+P1E]/[F+G+P21])	sej/yr	0.81	1.02	0.34
IME/E	Emergy Imports/Exports ([F+G+P21]/[G'+N2+P1E])	sej/yr	1.23	0.98	2.98
ED	Empower density (Total emergy used/ Area)	sej/year m^2	7.46E+11	8.78E+11	1.69E+12
EUP	Emergy per capita (U/population)	sej/person	1.57E+16	8.21E+15	1.28E+16
R/Population	Renewable flow per capita	sej/person	5.99E+15	2.69E+15	2.15E+15
R/U	Fraction use, locally renewable (R/U) %		38.01%	32.75%	16.84%
(F+G+P21)/U	Purchased fraction/% (F+G+P21)/ U		2.90%	4.80%	37.47%
N/U	Indigenous nonrenewable resources / total emergy use, %		59.09%	62.46%	45.69%
R+N	Indigenous sources	sej/yr	1.67E+23	1.92E+23	2.43E+23
ESR	Emergy self-support ratio (R+N/total emergy used (U),%	sej/yr	97.10%	95.20%	62.53%
EMR	Emergy to money ratio (Total emergy used, U/ GDP)	sej/$	3.45E+13	6.27E+12	5.80E+12
EIR	Emergy Investment Ratio ([F+G+P21]/[R+N])		0.03	0.05	0.60
EYR	Emergy Yield Ratio (U/F+G+P21)		34.49	20.84	2.67
ELR	Environmental Loading Ratio (N0+N1+F+G+P21)/R		1.63	2.05	4.94
ESI	Emergy sustainability Index (EYR/ELR)		21.15	10.15	0.54
Total fuel use/ Pop	Fuel use per capita (total fuel use)/ population	sej/yr capita	4.02E+13	3.51E+13	6.22E+13
Elec. /U	Ratio of electricity to total emergy use , %		3.27%	3.36%	2.92%
Exported emergy/GDP	Exported emergy/ Gross Domestic Product		8.14E+11	3.07E+11	7.30E+11
P21/U	Fraction import service (imported services/total emergy used, %)		0.42%	1.83%	33.85%
R/U*Pop	Renewable carrying capacity at present living standard		4.14E+06	8.06E+06	5.12E+06
8(R/U*Pop)	Developed carrying capacity at same living standard		3.31E+07	6.44E+07	4.10E+07
Additional Information of Ghana's economy					
Land Area m^2			2.30E+11	2.30E+11	2.30E+11
Population			1.09E+07	2.46E+07	3.04E+07
Gross Domestic Product (GDP, $)			4.98E+09	3.22E+10	6.70E+10
Fuel(Internal Consumption)		seJ/yr	4.38E+20	8.64E+20	1.89E+21
Electricity(Internal Consumption)		seJ/yr	5.60E+21	6.78E+21	1.13E+22

4.2 Resource Accounting

4.2.1 Total Emergy Use (U)

Total Emergy Use (U) is the sum of resource emergy inputs from indigenous extraction and imports, providing a preliminary evaluation of the total quantity of emergy used up in a system. However, since a substantial amount of indigenous extracted resources are exported, the Total Emergy Use (U) indicator is restricted in reflecting the quantity of materials consumed locally.

Total emergy use (U) increased by 126.53%, from 1.72E+23seJ in 2000, 2.02E+23seJ in 2010, to 3.89E+23seJ in 2019 (Table 4). The upward trend of total emergy use is attributed to increasing indigenous nonrenewable resources emergy flow and import emergy. Indigenous nonrenewable emergy flow (the largest contributor to total emergy use) increased by 75.16%, from 1.01E+23seJ in 2000 to 1.75E+23seJ in 2019 due to significant government and foreign direct investment in agriculture and extractive industries, boosting the quantity of resources produced. Indigenous nonrenewable resources contribution to total emergy use (N/U) declined from 59.09% to 45.69%, whereas import emergy contribution to total emergy use (F+G+P21/U) increased from 2.90% to 37.47 over the 19 years study period (Table 4). Ghana has also made significant progress in opening up its economy by lowering import tariffs, licensing, and removing barriers to trade by joining international organizations such as ECOWAS (Economic Community of West African States). The ECOWAS Common External Tariff (CET), implemented in 2007, is typical, which required Ghana to reduce its import tariffs for member ECOWAS states. Imports from ECOWAS member nations had rates ranging from 8% to 20%, whereas imports from non-member states had rates ranging from 10% to 25% (Brafu-Insaidoo & Obeng, 2008; Nomfundo & Odhiambo, 2017). The ECOWAS CET composed of four tariff bands; 1) 0% - on essential social goods; 2) 5% - on raw materials; 3) 10% - on intermediate goods; 4) 20% on finished goods ("ECOWAS Trade Information System (ECOTIS)" n. d.). These tariffs adjustments contributed to the 28.27-fold increase in import emergy, illustrating an evident transitioning from high dependence on indigenous resources to a growing reliance on purchased resources to drive economic growth. The dominant emergy flows for Ghana's socioeconomic system from 2000, 2010 to 2019 are shown in Figure 10.

4.2.2 Renewable resources (R)

Solar radiation, wind energy, rain (chemical and geo-potential energy), deep heat, and tidal energy were the renewable energies accounted in this study. Data on waves was unavailable hence ignored. Renewable resources contribution to total emergy use (R/U) declined from 38.01% in 2000, 32.75% in 2010, to 16.84% in 2019 (Table 4). Solar radiation accounted for the largest renewable emergy flow, which remained unchanged over the 19 years (2.50E+22seJ). The variation in renewable resources emergy flow calculated depends solely on the chemical potential (+2.07%) and geo-potential energy (-2.17%) of annual rainfall in 2010, which averaged 1227.1mm.

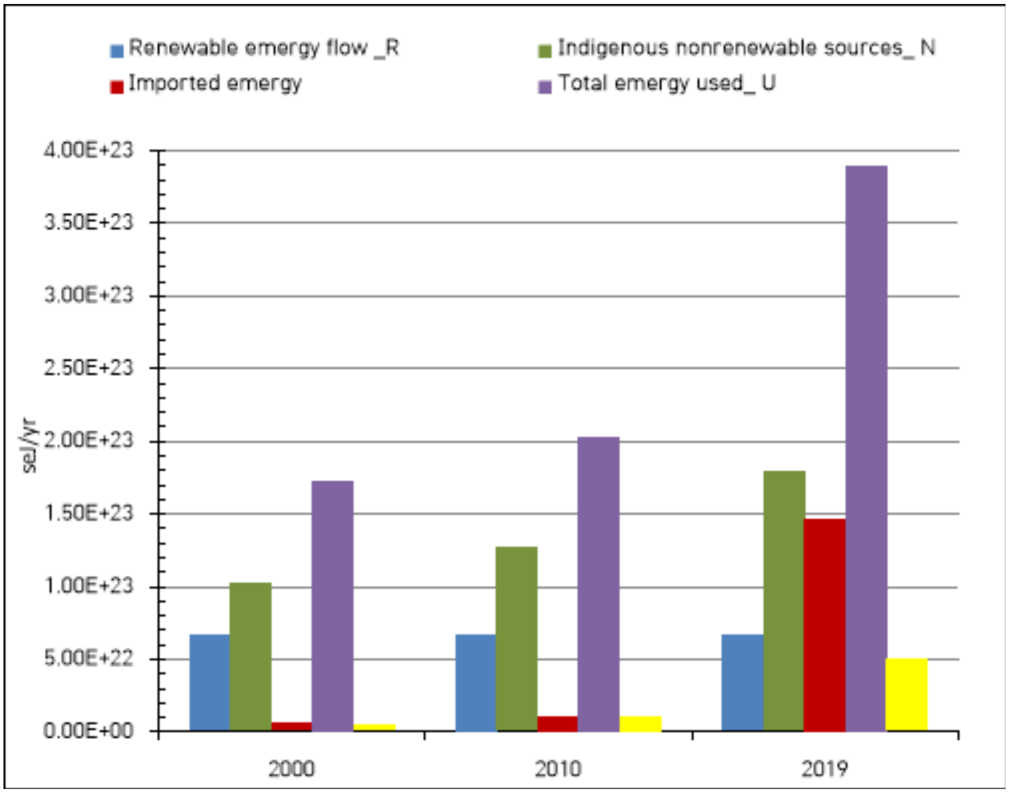

Figure 10. Trend of emergy flows of Ghana from 2000 to 2019.

4.2.3 Indigenous Nonrenewable resources (N)

The largest input of total indigenous nonrenewable resources (N) was dispersed rural resources (N_0) which declined from 91.46% to 73.6% of total indigenous nonrenewable resources in 2000 and 2019 respectively. The dominant emergy flows of dispersed rural resources were Poultry and Livestock (1.23E+23seJ), Fisheries (3.23E+22seJ), Hydroelectricity (7.80E+21seJ), Biomass (3.72E+21seJ) and Fruits and Vegetables (2.21E+21seJ). Despite the significant contribution of fruits and vegetable emergy production, it declined by 42.72% during the investigated period. Cash crops showed a fluctuating decreasing trend from 9.91E+17 in 2000, 1.65E+18 in 2010 to 8.24E+17seJ in 2019 (Figure 11). Additionally, in

(Figure 12), timber emergy production declined by 99.47% from 2.82E+21 in 2000 to 1.50E+19 in 2019 primarily due to dwindling of Ghana's timber resource base.

Declining Fruits and Vegetable emergy production

Fruits and vegetable production declined within the 19 years study period due to drastic consumption decline. According to Graphic Online (March 09, 2017), the average Ghanaian consumes % of fruits and 2.3 % of vegetables daily, compared to the WHO recommendation of 4 to 6 %, owing to the high cost of fruits and vegetables, which discourages consumption and production to the greatest extent. Furthermore, the bulk of vegetable cultivation in Ghana is done under rain-fed circumstances without irrigation, which impacts production levels, especially during the dry seasons. Also, the fruit and vegetable industry lacks ready market i.e., processing industries, to consume production. These factors partly contributed to the slump in fruits and vegetable emergy production observed in the study.

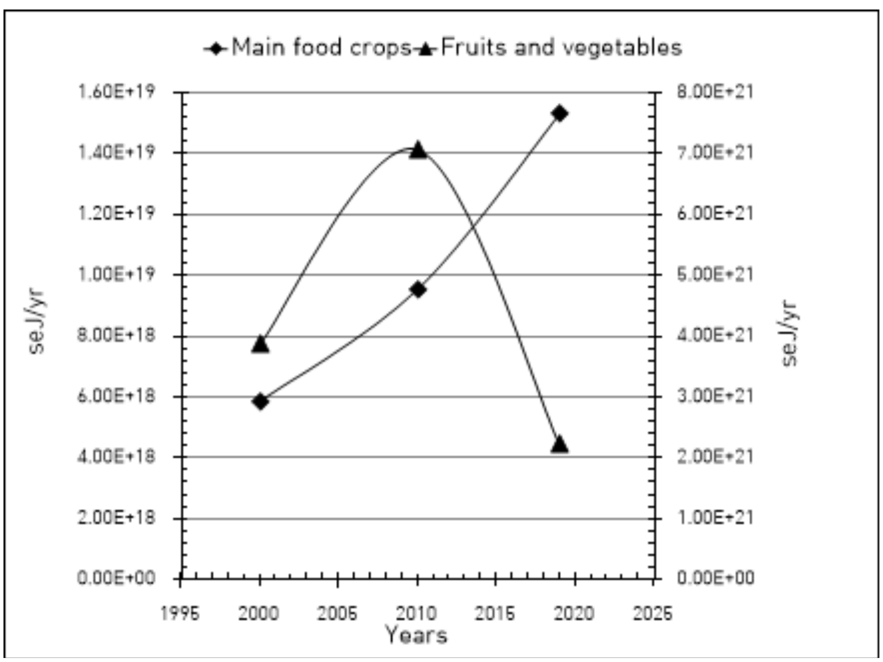

Figure 11. Main food crops & fruits/vegetables emergy production from 2000 to 2019.

Dwindling Timber Resource base

Illegal logging and mining activities are partly attributed to the dwindling timber resource base as reflected in the decline of timber emergy production, particularly from 2010 to 2019 (-99.62%). Ghana's timber resource base is challenged by weak law enforcement on forest protection, making it possible for illegal logging activities in forest reserves. Additionally, agricultural activities have intensified in recent years, resulting in the loss of forest areas. Acheampong et al. (2019) reported that the expansion of agricultural activities such as food crop farms resulted in a 78% loss of forest reserves between 1986 and 2015. However, the Ghana Forestry Commission has lately undertaken Afforestation and Re-afforestation Programs in collaboration with other non-governmental organizations to restore the diminishing timber resource base. As part of the Afforestation programme, farmers are allocated degraded forest lands to cultivate their crops together with tree crops (Acheampong et al., 2019). Considering the immense revenue derived from timber exports, it is pertinent that the government of Ghana undertake additional measures to replenish the dwindling timber resource base.

Increasing poultry, livestock and fisheries resource base

Governmental support, such as reduced import levies on poultry feed, vaccinations, drugs, and enhanced veterinary services, led to a significant rise in poultry and livestock emergy production (+73.77%). In recent years, government agricultural flagship programmes such as "Planting for Food & Jobs" aimed at creating food security and more efficient production in poultry and livestock production to meet domestic consumption and feed the local agro-processing industries. Fisheries emergy production increased by 2.21% throughout the investigated period partly due to increasing commercial operations, which account for 75% of local production since 2010 (MOFAD, 2015; Doku et al., 2018).

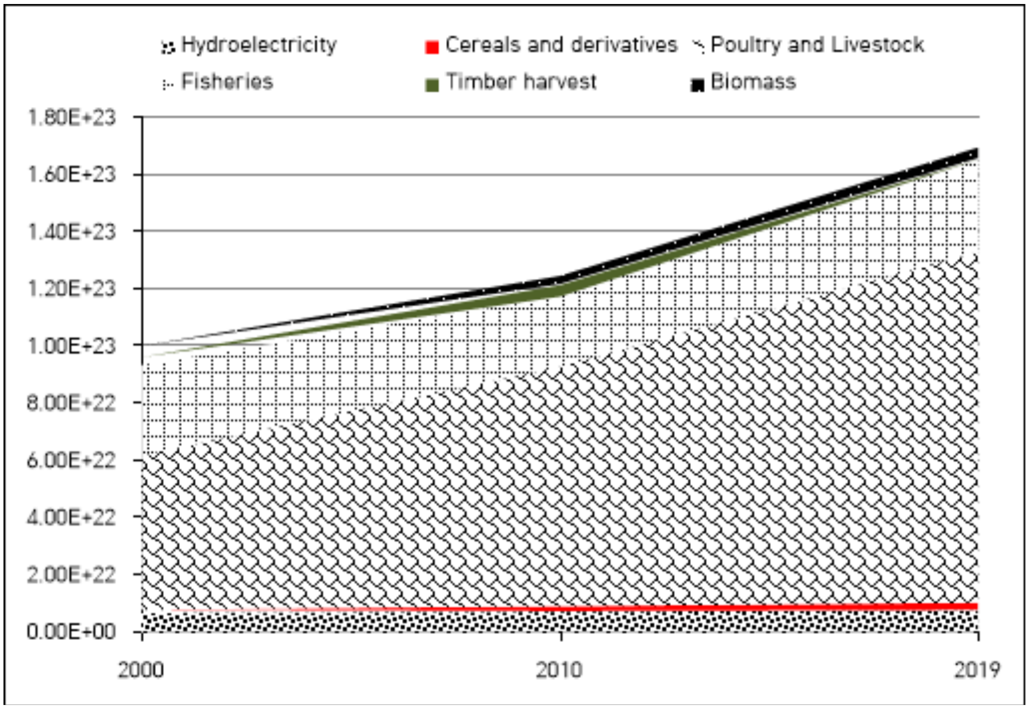

Figure 12. Trend of Indigenous dispersed rural resources (N0) from 2000 to 2019.

4.2.3.1 Concentrated Nonrenewable Production (N1)

Contribution of concentrated nonrenewable production (N1) to indigenous nonrenewable resources increased from 8.54% to 26.34% in 2000 and 2019 respectively. The largest input category of (N_1) was raw minerals which increased from 1.62E+21seJ in 2000 to 1.10E+22seJ (+5.9 times) (Figure 13). The rising trend of raw minerals is attributable to increase in the production of gold (+98.17%), bauxite (122.22%) and manganese (+813.79%) over the 19 years period (Table 3). However, diamond production declined by 95.59% from 2.66E+14seJ in 2000 to 1.44E+13seJ in 2019.

Slump of aluminum production

Between 2007 and 2011, a 200,000 tonne per year aluminum smelter of Valco (Volta Aluminum Company Limited), a state-owned aluminum company, was shut down due to operational inefficiencies; mainly power shortages and weak metal prices (Kpodo, K. 2010), resulting in a 72.31 % drop in aluminum emergy flow. However, steel emergy flow remained unchanged, producing 5.65E+19 in 2010 and 2019. This variation caused the fluctuating trend of metals emergy flow, which declined by 25.64% from 1.21E+20seJ in 2000 to 9.00E+19seJ in 2019. However, it is still unclear how private aluminum companies contributed to the slump of aluminum production in 2010. This variation caused the fluctuating trend of metals emergy flow, which declined by 25.64% from 1.21E+20seJ in 2000 to 9.00E+19seJ in 2019. Pertinently, a concerted attempt must be taken to increase aluminum production to remain relevant to Ghana's socioeconomic system's growth.

The third-largest input category of concentrated nonrenewable production was fossil fuels (oil and natural gas) which accounted for 2.79E+22seJ in 2019. Ghana started crude oil exploitation and production in late 2010. Oil and natural gas rents of GDP have substantially increased, averaging 3.63% and 0.08% annually between 2011 and 2019. Fossil fuels accounted for 15.70 % of indigenous nonrenewable emergy flow in 2019, surpassing minerals and metals, which accounted for 6.20 % and 0.05 %. Topsoil loss, the minor input of (N_0), remained unchanged over the 19 years, accounting for less than 1% of total indigenous nonrenewable emergy flows (N). Despite the slump in aluminum, diamond, timber, cash crops, fruits, and vegetable production, indigenous nonrenewable emergy flows increased by 75.16%, accounting for 45.69% of total emergy use in 2019.

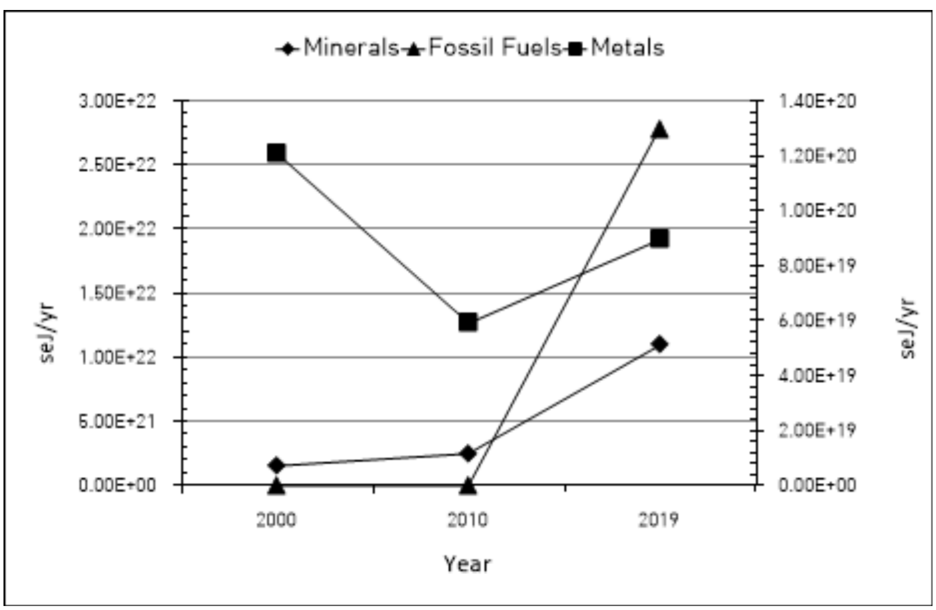

Figure 18. Trend of Concentrated nonrenewable resources (N1) from 2000 to 2019.

4.2.4 Import and Export Emergy Exchange

4.2.4.1 Import Emergy

Total import emergy increased from 4.98E+21seJ to 1.46E+23seJ (28.27 times) while total export emergy increased from 4.05E+21seJ to 4.89E+22seJ (11.06 times) from 2000 to 2019. It can be argued that Ghana's rising import tendency is mainly attributable to the over-liberation of the Ghanaian economy due to policy adjustments and multilateral trade agreements. Despite the fluctuations in total import emergy, import emergy has been substantially higher than export emergy over the 19 years. In monetary terms ($ exports/ $ imports), Ghana traded at a deficit in 2000 (0.81) and 2019(0.34) but for 2010(1.02). However, Ghana fared better than its trading partners, with more emergy imported than emergy exported.

Among imports, manufactured goods expressed as "G" in (Table 4) dominated Ghana's imports until 2010, accounting for 70.93% and 49.67% of total imports in 2000 and 2010, respectively. In past decades Ghana has struggled to develop manufacturing industries that add value to its indigenous resources forcing it to rely on imports from external markets, mainly; Europe, China, and other African countries.

Increasing Import-dependency for Construction Materials, Plastic and Fertilizers

Among manufactured goods, construction materials increased by 312% from 2.35E+21seJ in 2000 to 9.68E+21seJ in 2019 (Figure 14). Growth in imports of construction materials is attributed to massive infrastructural developments (civil works and real estate) that have been ongoing since 2010, depicted by the increase in built up areas in (Figure 5). The government flagship programme "One district One factory" implemented in 2017, has substantially increased imports of construction materials considering the fact that as of November 2021, the initiative had 150 factory projects at various stages of construction across the country.

Plastic and synthetic rubber imports grew 2.68 times, from 4.50E+20seJ in 2000 to 1.66E+21seJ in 2019 (Table 3). This is attributable to local plastics manufacturers facing hefty taxes, resulting in the importation of finished plastics due to the high pricing of locally manufactured ones (Opoku-Agyemang, 2017). Food and agricultural products increased by

2.32times, whereas machinery and transport equipment imports grew by 3.41 times, being 2.18E+16seJ to 9.62E+16seJ over the 19 years (Figure 15). This noted growth in machinery and transport equipment is attributed to increased mechanized farming and imports of pre-owned and new vehicles and automobile repair parts. This increasing trend of import-dependency for manufactured goods without corresponding infrastructure makes Ghana's economic system susceptible to markets shocks and exchange rate depreciation.

Declining import-dependency for electricity

However, import emergy of electricity declined by 85%, illustrating the decreasing trend of import-dependency for electricity. Energy Commission of Ghana (2019) indicated that Ghana's electricity import dependency rate declined from 13.07% to 0.9% in 2000 and 2010. This performance in the electricity sector is attributed to the generation of electricity from renewable resources to support the national grid. Typical is the installation of a 20MW solar plant in Navrongro, Upper East region, in 2013 and a 100kilowatts biogas plant. This suggests that Ghana can be electricity self-sufficient if consistent efforts are made to improve its renewable energy sector.

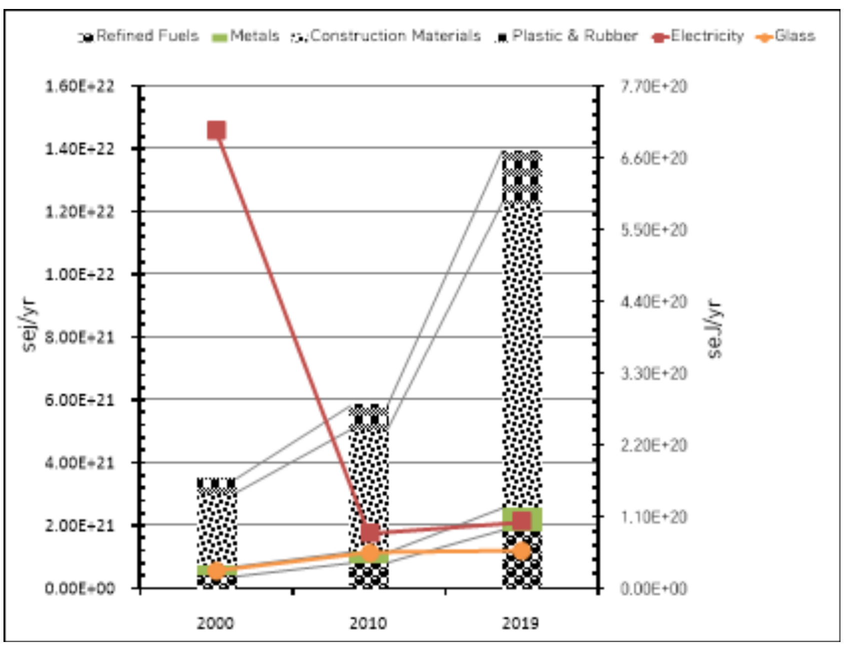

Figure 14. Import emergy flows from 2000 to 2019.

Among refined fuels, LPG, gasoline, gas oil increased drastically by 6.67times, 2.27 times, and 3.80 times, respectively, over the past 19 years, illustrating an increasing trend of import-dependency for refined fuels. This is due to the growing demand for fuel products and operational inefficiencies of its domestic refinery industry. Due to poor maintenance and periodic shutdown, the only oil refinery; Tema Oil Refinery (TOR), which is meant to produce 45,000 barrels per day, is underutilized and unable to meet local demand.

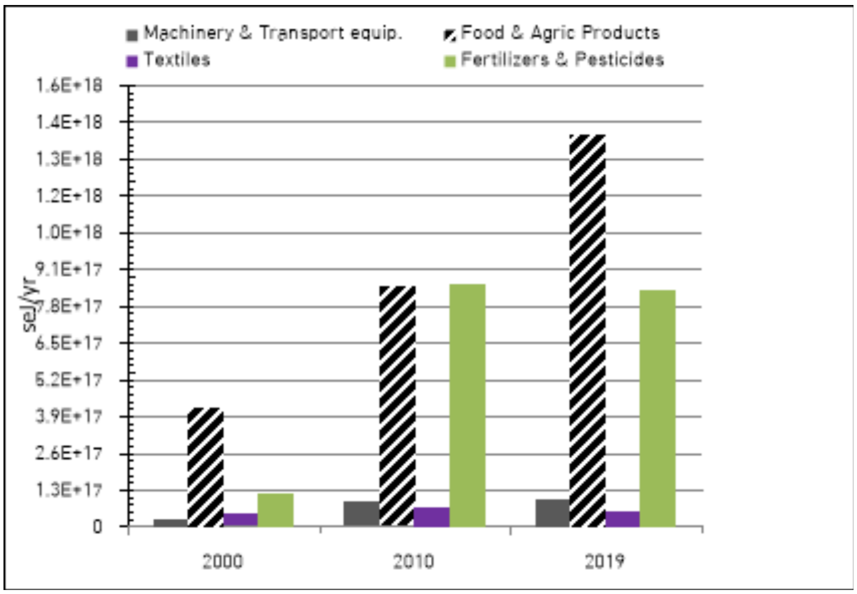

Figure 15. Import emergy from 2000 to 2019.

Service imports

In 2019, import services dominated import emergy flow, increasing by 182.2 times from 2000. Business services imports accounted for the largest input category representing USD1.09billion, 53% of total import services, surpassing its contribution in 2010, i.e., USD 618million, 20% of total import services. The government of Ghana announced a national agenda-themed "Ghana Beyond Aid" in 2017 to expedite economic growth and transformation by harnessing the country's natural and human capital effectively and reducing foreign-aid dependency to the bare minimum. One of the initiative's objectives is to make Ghana an attractive investment hub for foreign private finance and investments to industrialize its extractive and agriculture sectors. This can be attributed to the increasing trend of business services import and further reflects Ghana's economy's increasing openness and influx of foreign investment. Government services (financial, insurance, security services) accounted for 19% of total imports in 2019. Paid services (transport) to bring in manufactured goods, refined fuels, agricultural products, and whatnot accounted for 17.08% of total service imports (OEC, 2019). The proportion of export services to total exported emergy increased from 2.13E+21seJ to 3.69E+22seJ (+2.46%) in 2000 and 2019. Despite the increase in export services, it fell behind import services in 2019 (Figure 16).

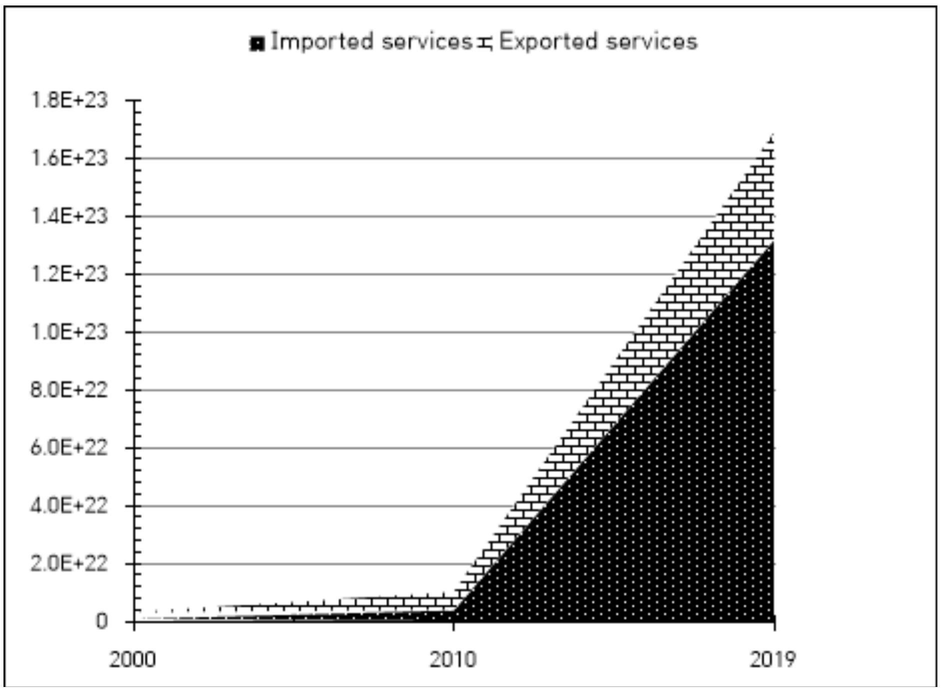

Figure 16. Services import and export emergy flow from 2000 to 2019.

4.2.4.2 Export Emergy flow

Concomitant to increasing indigenous nonrenewable resources, export emergy increased by 11.06 folds, from 4.05E+21seJ in 2000 to 4.89E+22seJ in 2019. Export services have been the dominant emergy flow of total export emergy increasing from 52.46% to 75.52% (+43.95%) over the 19 years. This dominance is attributable to Ghana's burgeoning tourism industry. International tourist expenditure averaged 9.8% of total exports between 2000 and 2019, providing USD 1.9 billion in 2019. (OEC, 2019). N_2 was the second largest contributor to total exported emergy over the 19 years period with an increase from

1.57E+21seJ in 2000 to 1.08E+22seJ in 2019 (5.8 fold-increase). However, N_2 share of total exports illustrates a declining trend from 38.65% to 22.03% in 2000 and 2019 respectively. Apart from N_2 and export services, timber extraction, textiles, LPG, and heavy oil declined by 25.21%, 0.88 times, 0.87 times , 0.32 times respectively. In addition, significant increments to exports over the 19years were food and agricultural products (2.76 times), plastic and synthetic rubber (4.33 times) and electricity (2.65 times).

In summary, Ghana's imported emergy exceeded its exported emergy in 2000 and 2019, but not in 2010. Ghana's trade surplus in 2010 is attributed to Ghana alternating between its tariff system and the ECOWAS CET (Roquefeuil et al., 2014; Orkoh, 2018). Between 2007 and 2011, the government imposed its tariffs, which were adjusted upwards than the ECOWAS CET, raising import duties and reflecting a decline in imported emergy in 2010. However, Ghana re-adopted the ECOWAS CET in 2015. In international exchange, Ghana fared better than its trading partners, with more emergy imported than emergy exported.

What conclusions can be drawn about Ghana's socioeconomic system based on the emergy-based performance indicators? What is the well-being of the Ghanaian people? What has been Ghana's performance in international trade? Is Ghana's socioeconomic system sustainable? The next section of the chapter gives a detailed interpretation of the emergy-based performance indicators to help provide a framework of reference for policymaking.

4.3 Interpretation and Discussion of Emergy-Based Performance Indicators of Ghana

4.3.1 Emergy use per person (EC)

Emergy use per person (EC) indicated approximately 18% drop in the amount of geobiosphere resources invested in each person in 2019 compared to 2000. EC declined from 1.57E+16seJ/person in 2000 to 1.28E+16seJ/person in 2019, with the least in 2010, 8.21E+15seJ/person, attributable to increasing population size and uneven distribution of economic resources. Population increased by 178.78% as against a 126.53% increase in total emergy use over the same period. The decline in EC does not necessarily depict a drop in living standards due to significant rise in economic and industrial activities (reflected by the Empower indicator) observed in the investigated period. In Ghana, disparity in employment distribution and economic resources partly affects the quantity of resources consumed per person. In 2010, the services sector share of GDP was approximately 51% while the agriculture sector declined to 21.3% (GSS, 2013). This decline in agriculture widened the income gap and access to infrastructure between urban and rural dwellers since most services and industrial jobs are concentrated in the urban areas considering that as of 2010, rural population accounted for 49.3%. Meanwhile, the informal sector accounted for 86% of Ghana's total workforce, posing significant challenges in terms of job security, revenue production, and resource consumption, especially as 69.4 % of informal workers resided in rural regions.

As shown in (Figure 17), emergy use per person increased by 102.26% from 2010 to 2019, partly due to government measures aimed at equitable and long-term poverty reduction in rural Ghana. A policy such as the Northern Rural Growth Programme (NRGP) is being funded to the tune of USD 94.39million. The programme seeks to increase household income and livelihood in Northern Ghana (African Development Bank, 2019). Furthermore, according to Ghana Statistical Service (2018), the informal workforce fell from 86.2 percent to 59.9 %, while the formal sector expanded from 13.8% to 40.1 %, resulting in a considerable boost in income creation and employment stability. This increased the consumption of resources, goods and services and overall boost in real living conditions as reflected in emergy use per person indicator for 2019. However, comparing emergy use per person to GNP per person economic indicator revealed a mismatch. Whereas emergy use per person dropped by 0.18 times, GNP per person increased by 7.7 times from USD$258.47 to USD$2, 246.62 in the investigated period, reinforcing the idea that the emergy use per person gives a clearer perspective of the actual living standard of a population. Despite indigenous sources increasing by 75.16% (Table 4) in the investigated period, renewable emergy use per person indicates a declining trend (-27.42%) indicating low-intensity utilization of renewable sources (Figure 17). With Ghana's population growing, policymakers must implement measures to harness and increase the amount of renewable resources consumed per Ghanaian to improve their real well-being. Fuel use per person increased by 54.72% partly due to increased movement and population growth.

Compared with developing countries, the real welfare of the Ghanaian population in 2019 was 6 times, 2.5 times, 4 times, and 8 times superior to Rwanda, Thailand, Ecuador and Liberia respectively (Table 5). Moreover, in developed countries, Ghana's EC in 2019 was inferior to Canada (2011), Portugal (2009), and Italy (2008). Thus, a Ghanaian in 2019 was living on approximately one-fourth the wealth of an Italian in 2008 (Campbell & Ohrt 2009; Rutebuka et al., 2018).

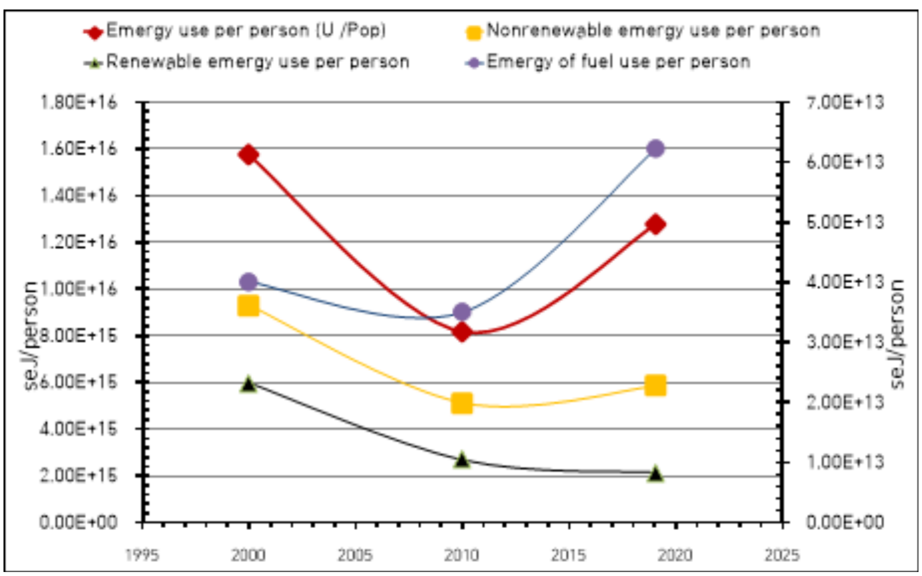

Figure 17. Trend of Emergy use per person of Ghana from 2000 to 2019.

Table 5 Emergy performance indicators of Ghana and other countries

Country	Total emergy use E20 sej/yr	Emergy use per capita E15 sej/person	Empower Density E11 sej/m²/yr	Emergy/Money Ratio E12 sej/USD	Emergy import/export	Emergy Self-Support Ratio %, (R+N)/U	Environmental Loading Ratio, ELR	Electricity fraction/%	Emergy Sustainability Index ,ESI	Renewable Fraction/%
Ghana (2019)*	3,890	12.8	16.90	5.80	2.98	62.53	4.94	2.92	0.54	16.84
Rwanda (2016) [a]	631	5.30	23.97	7.54	3.38	54	0.86	1.4	2.52	53.76
Indonesia (2015) [b]	15,300	5.91	64.9	2.44	0.36	155.15	4.93	11.76	0.65	16.8
Malaysia (2015) [b]	6,350	27	769	2.94	1.1	83.53	23.65	18.14	0.05	4.05
Philippines (2015) [b]	4,820	4.75	86.2	2.27	2.62	64.26	6.44	13.13	0.27	13.44
Puerto Rico (2013)[c]	5,130	140	580	2.56	#	60	8.09	#	0.11	11
Canada(2011) [d]	57,200	173	5.99	4.22	0.46	76	2.3	#	1.59	#
Portugal (2009) [e]	14,500	136	157	1.18	0.97	54	22.57	4	0.10	4.38
Brazil (2007) [f]	77,400	42.2	9.08	0.52	0.48	85	1.49	8	4.48	40.20
Italy (2008) [g]	33,700	55.2	110	2.15	1.6	#	15.8	#	0.09	#
China(2004) [h]	192,400	15.3	20.76	12	0.64	81	9.29	8.84	#	9.64
Sweden (2002) [i]	3,695	41.3	8.99	0.158	1.16	17.3	#	0.14	#	12.2
Australia [h]	8,850	59	1.42	6.4	0.39	92	0.86	6.8	#	#
Dominica [h]	7	13	8.8	14.9	0.84	69	2.67	<0.01	#	#
Ecuador [h]	964	10.7	3.4	8.7	0.2	94	0.54	32	#	#
India [h]	6,750	1	2.05	6.4	1.45	88	1.02	10	#	#
Japan [h]	15,300	12.6	41.09	2.14	4.2	31	8.34	2.61	#	#
Liberia [h]	465	26	4.1	34.5	0.15	92	0.09	1	#	#
Netherlands [h]	3,702	26	100	2.2	4.3	23	15.9	10	#	#
New Zealand [h]	791	26	1.94	3	0.76	60	0.81	15	#	#
Papua New Guinea[h]	1,216	35	2.63	48	0.09	96	0.15	0.8	#	#
Poland [h]	964	9.6	10.6	6	0.65	66	19.78	18	#	#
Spain [h]	2,090	6	3.12	1.6	2.3	24	7.2	22	#	#
Switzerland [h]	733	12	17.7	0.7	3.2	19	7.44	32	#	#
Thailand [h]	1,509	3.2	2.15	3.7	0.54	70	1.04	10.8	#	#
USA [h]	117,800	41.9	1.19	12.53	1.27	72	5.85	3.8	#	#

Source: * This Study, [a] Rutebuka et al.(2018), [b] Yang et al. (2020), [c]González-Mejía & Ma (2017), [d] Hossani et al.(2013), [e] Oliveira et al.(2012), [f] Giannetti et al.(2013) [g]Pereira et al.(2010), [h]Jiang et al.(2008), [i] Hagström et al. (2004).

4.3.2 Empower density (ED); Total Emergy Use and Land Area

Empower density increased by 126.53% from 7.46E+11seJ/m2 in 2000 to 1.69E+12seJ/m2 in 2019 (Table 4), which indicates more intensity of economic activities, industrialization, and land usage in Ghana. As shown in (Figure 18), a substantial rise in empower density occurred between 2010 and 2019 (+92.53), which correlates directly with; 1 the increase in built-up areas during the same period from 1941.70km^2 to 3,098.545km^2 (+60%); 2) significant rise in actual living standards as EC increased by 55.80% from 2010 to 2019. The rising trend of empower density is aligned with the current industrial and economic development in Ghana. Since 2000, successive governments have prioritized private-led industrial development by projecting Ghana as an investment hub, a sharp contrast to the previous industrial strategies which premised on state-led industrialization, protectionism of domestic industries and small-medium enterprises, and import substitutions strategies between 1960 and 1990 (Aryeetey & Fenny, 2017). The resultant effects of the current private sector-led industrialization have been modest, with the industrial sector contributing an average share of 25% to GDP from 1995 to 2019 (World Bank, 2019).

One striking feature is the dynamic growth of subsectors within the industrial sector. The growth of the manufacturing sector lost its dominance to the construction subsector, with the former declining from 10.2% to 4.6%, whiles the latter expanded rapidly by 40% between 2006 and 2016 (GSS, 2018), signaling increased construction activities. The mining and quarrying sector expanded from 2.8% to 4.2%, primarily due to oil and natural gas production. The industrial sector is estimated to grow by 20.3%, driven by the construction sector and infrastructural investment in the oil and natural gas subsector (Owoo & Page, 2017). Furthermore, the rising ED in 2019 indicates that land-use problems may become more prevalent, impeding potential industrial and economic development. Compared with some developing countries such as Liberia, Brazil (2007), Papua New Guinea, and Thailand (Table 5), Ghana was more concentrated in emergy use and possibly a higher degree of industrial development, particularly between 2010 and 2019 compared to the aforementioned countries.

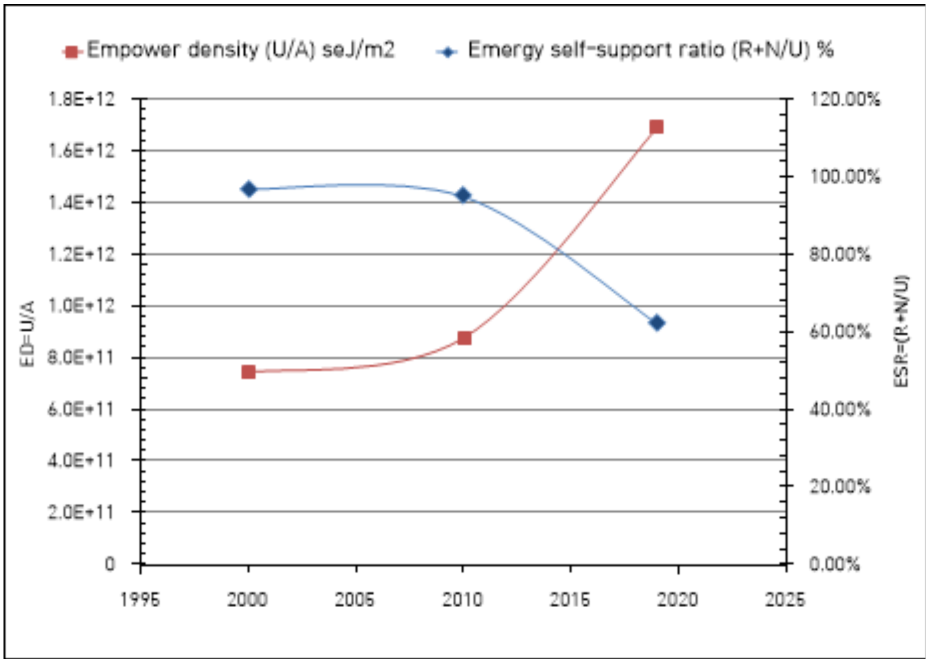

Figure 18. Empower density & Emergy self-support ratio from 2000 to 2019.

4.3.3 Emergy Self-support Ratio (ESR)

ESR declined by 35.61% from 97.10% in 2000 to 62.53% in 2019 (Table 4). The ESR value in 2019 implies that approximately 62% of resources consumed in Ghana came from sources within the national border, with the remaining emergy demand generated from purchased resources, which is indicative of Ghana's growing reliance on external resource inputs compared to 2000. Closely related to the weakening capacity of Ghana's self-sufficiency is the declining trend of renewable emergy use per capita (Figure 17), suggesting less intensity utilization of Ghana renewable resources. It is imperative that future economic and industrial development efficiently harness the utilization of Ghana's renewable resources to the maximum possible extent, especially in the energy sector. Compared to other developing countries in (Table 5); Ghana's ESR in 2019 (62.53%) shows weakening self-sufficiency. Ghana's long-term emergy demand will be primarily anchored on purchased resources if the current trend persists. Ghana's self-sufficiency capacity in 2019 was inferior to developing countries like Indonesia (155%), Papua New Guinea (96%), Liberia (92%), Ecuador (94%), and Thailand (70%), implying that the above- mentioned countries are likely to use internal resources intensively.

4.3.4 Emergy to money ratio (EMR)

The EMR values indicate less emergy use per unit of currency circulation due to declining intensity utilization of local resources and gradual diversification of the economy. The trend of Ghana's emergy to money ratio is expressed in both USD$ and Ghana cedi (GH₵), (Figure 19). Both curves demonstrate a downward pattern during the investigated period, implying that the emergy purchasing power of money was inferior in 2019 than in 2000; thus, the same amount of money in 2000 could purchase less emergy in 2019. As shown in (Table 4), Ghana's EMR decreased from 3.45E+13seJ/$ in 2000 to 5.80E+12seJ/$ in 2019 (-83.16%). The EMR indicator further measures inflation within a system. The EMR trend in Ghana is aligned with high inflation, which adversely affects the consumption of resources and the actual standard of living to a larger extent. Compared with other developing countries in (Table 5), Rwanda (2016), China (2004), Liberia, and Papua New Guinea use more free environmental resources than Ghana. Also, Ghana has relatively inferior purchasing power; thus, a dollar in Ghana can buy less-emergy commodities than the countries mentioned above.

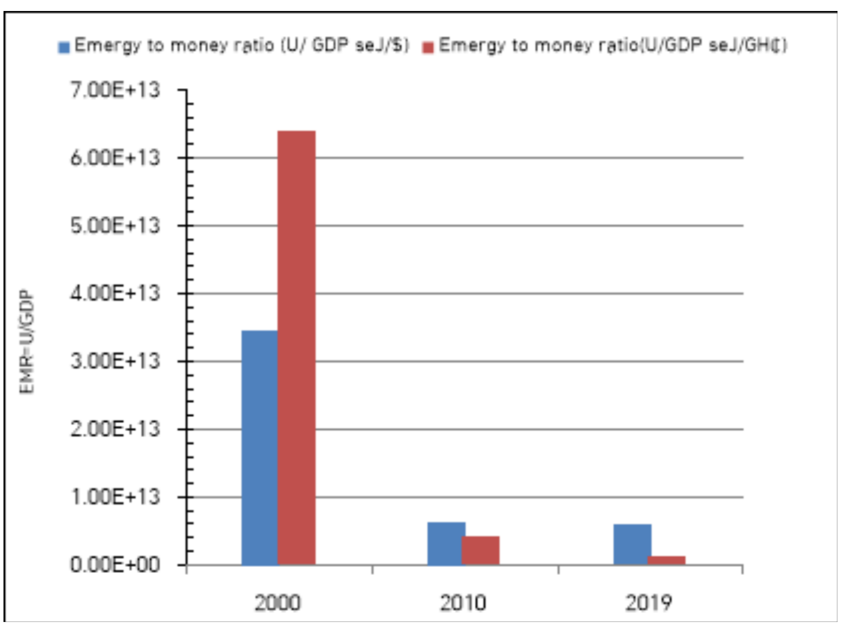

Figure 19. Trend of Emergy to money ratio from 2000 to 2019.

4.3.5 Emergy Exchange Ratio (EER)

Emergy Exchange Ratio, (EER) suggests that Ghana traded at an advantage in foreign trade in 2000 and 2019, importing high-emergy commodities per unit of less-emergy commodities exports. One index for assessing the economic performance of economies is the "Terms of Trade" denoted as export prices/import prices. The "Terms of trade" indicator measures a country's economic dependency on imports but fails to account for the "hidden imports" embodied in the products (Lomas et al., 2007; Pereira et al., 2010). Emergy Exchange Ratio is the most comprehensive indicator to evaluate traded resources among nations rather than "Terms of Trade." Emergy Exchange Ratio denoted as export emergy/import emergy, measures degree of gains or losses in foreign trade. The EER indicator revealed that Ghana received more emergy in trade in both 2019 and 2000 but had emergy losses in 2010 (Table 4). Ghana received 58% net emergy flow in the investigated period, signaling that Ghana traded at an advantage and benefited more in foreign trade but not in 2010 (Figure 20). In 2010, Ghana made several import tariff adjustments that affected the flow of import emergy; including 1) withdrawal from the ECOWAS Common External Tariff on imports, and 2) upward adjustment of import tariffs on manufactured and finished products, resulting in exporting more emergy per unit of import in that year. However, the bulk of Ghana's exports are mainly in unprocessed state with little or no qualitative differentiation across the global market, positioning Ghana at the least end of the global value chain in terms of economic benefits. In 2010, exports accounted f 29.5 %, while imports constituted 45.9 % (GSS, 2013), indicating that Ghana exported more embodied emergy than it received in economic benefits. It's worth mentioning that, in recent years, Ghana's governments have collaborated with industry stakeholders and development partners like UNIDO (United Nations Industrial Development Organization) to diversify the country's economy and make indigenous firms competitive in the global value chain. To sustain Ghana's economic growth, governments should continue to make steadfast efforts to transform exports into high-quality and finished goods to help propel the country's participation and benefits in foreign trade.

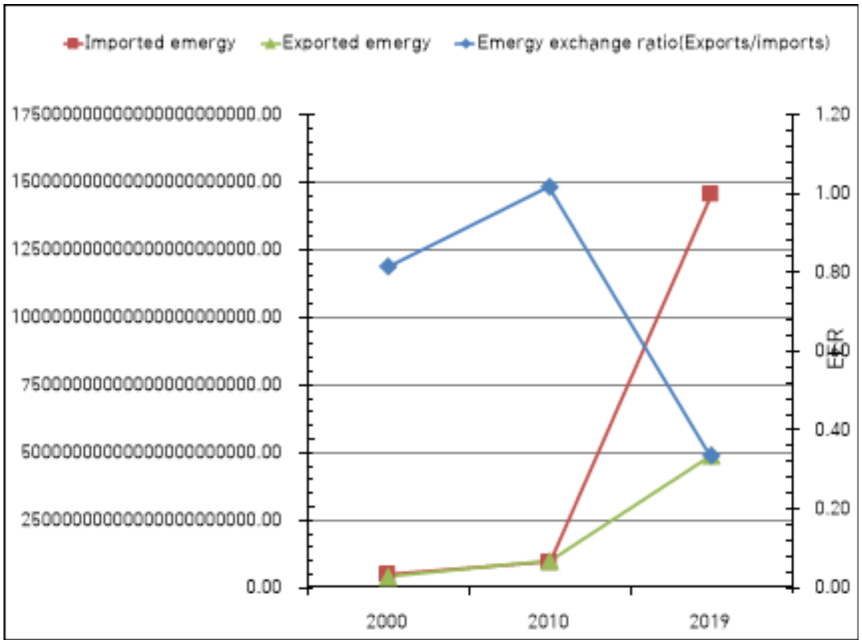

Figure 20. Trend of Emergy Exchange between Ghana and its trading partners.

4.3.6 Emergy Yield Ratio (EYR)

EYR indicator declined by 92.26% from 34.49 in 2000 to 2.67 in 2019 (Table 4). The development path signals a drastic decline in indigenous nonrenewable resources-dependency and growing reliance on purchased resources from external economies, rendering the Ghanaian socioeconomic system unsustainable (Figure 21). Furthermore, in terms of emergy exchange, the decreasing pattern of EYR suggests that Ghana is steadily gaining competitiveness in foreign trade and benefits more from its trading partners. The bulk of Ghana's imports are mainly characterized by high-emergy commodities (services, finished and manufactured goods) and exports less-emergy commodities (mostly unprocessed commodities).

4.3.6 Environmental Loading Ratio (ELR)

The rising trend of Ghana's environmental stress does not necessarily depict extreme exploitation of indigenous resources and storages but rather an indication of rising environmental stress imposed by purchased resources. Indigenous nonrenewable resources ratio to imports declined from 2037.67% in 2000 to 121% in 2019 while Ghana's emergy self-sufficiency ratio (ESR) declined from 97.10% to 62.53%. Import emergy compensated for the loss in self–sufficiency increasing from 2.90% to 37.4% in the study period. ELR of Ghana increased exponentially (2.03-fold) from 2000 to 2019 (Figure 21), further suggesting increased environmental stress imposed on the local ecosystem. When economic activity is created using nonrenewable and purchased resources, the environment of the economic activity no longer exists in its natural state but evolves into a human-influenced system in which indigenous resources play a minor role (Lou & Ulgiati, 2013). The bulk of the country's imports are characterized by high-emergy commodities, which transforms them to drive economic growth, imposing severe strain on the environment. The trend of Ghana's ELR reflects the increasing intensification of economic and industrial activities as highlighted by the Empower density (ED) indicator. According to Brown and Ulgiati (2004), "ELR < 10 suggests moderate environmental load while ELR >10 suggests high environmental load". Ghana's ELR values suggest moderate environmental load and performing better compared with other countries; Italy (15.8), China (9.29), Portugal (22.57), Malaysia (23.65), and Puerto Rico (8.09) [Table 5]. Nevertheless, it is still significant, and measures should be geared towards making industrial and economic activities more ecologically friendly.

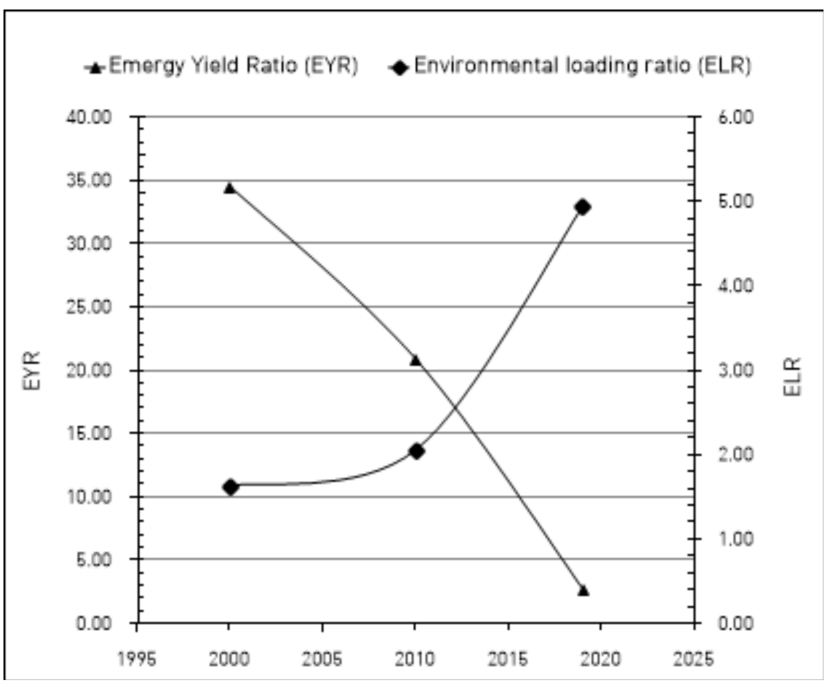

Figure 21. The variation of EYR and ELR from 2000 to 2019.

4.3.7 Emergy Sustainability Index (EmSI)

ESI values indicated an exponential decline in sustainability, categorizing Ghana's socioeconomic system as resource-consuming and low-environmental performance. Brown and Ulgiati (2004) suggests that systems with ESI values from 1 to 10 are environmentally sustainable while ESI values < 1 characterizes highly developed consumer-oriented systems characterized with import exceeding export emergy. The 97.44% reduction in ESI in the study period underlines that the emergy yield gained for the Ghanaian economy was inferior to the potential damage inflicted on its local ecosystem by foreign trade (Figure 22). ESI value in 2019 (0.54) suggests that Ghana is moving further away from being in equilibrium with its natural environment, necessitating a restructuring of industrial and economic activities. González-Mejía and Ma (2017) suggested that measures that reduce import emergy/export emergy and enhance local emergy generation will raise a system's ESI, steering it toward a more sustainable path. Among these practical suggestions, enhancing local emergy generation will propel Ghana towards long-term sustainability. Concerned policymakers should implement measures that add qualitative value to Ghana’s indigenous sources to create a local market coupled with harnessing and efficient usage of renewable resources while minimizing its nonrenewable and purchased resources dependency. Technological innovations that guarantee the recycling and reuse of its internal resources will significantly reduce import emergy and environmental strain.

4.3.8 Renewable Carrying Capacity

Ghana's capacity to optimally utilize its potential indigenous renewable sources is limited based on the renewability ratios observed in the study. In 2000, 38.01% of Ghana’s total population could have been supported by indigenous renewable sources (at a higher standard of living as shown by the emergy use per person indicator, EC). However, in 2019 only 16.84% of the total population could be supported by renewable sources owing to the combined effects of population increase (+178.9%), increasing trend of total emergy utilization (126.53%), and declining trend of renewable emergy use per person. Renewable carrying capacity increased by 23.55% from 4.14E+06 in 2000 to 5.12E+06 in 2019 (Figure 22). The development pattern of renewable carrying capacity implies that nonrenewable and purchased resources largely support the country's population and actual living standards. Despite a 0.35 % increase in renewable sources (Table 4), it clearly appears that there is less intensity utilization of renewable resources to support population and socioeconomic growth The developed carrying capacity at present living standards is calculated by multiplying the renewable carrying capacity by 8 (Campbell & Ohrt, 2009), yielding 4.10E+07 persons in 2019 (Table 4).

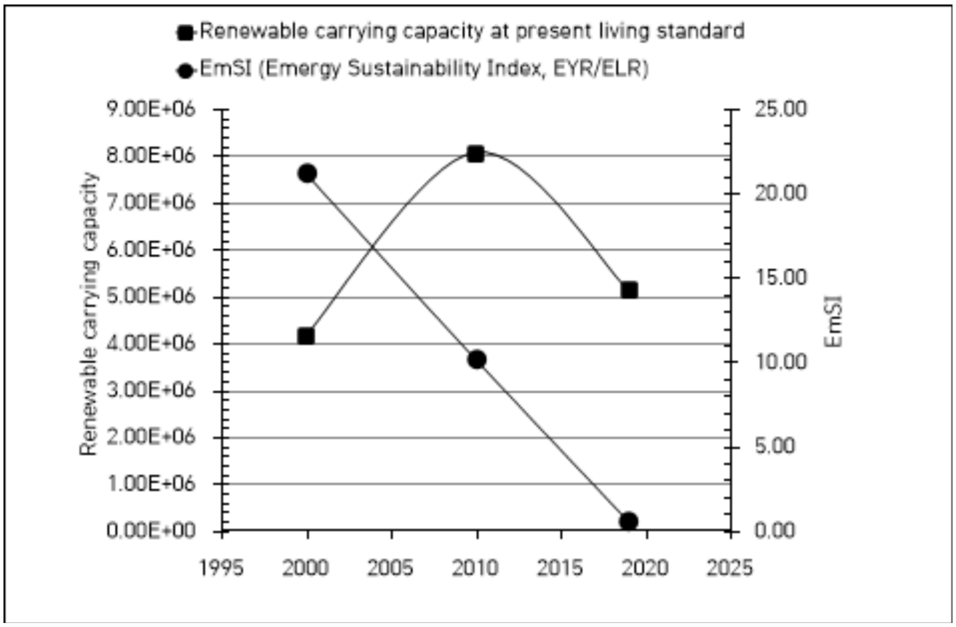

Figure 22. EmSI & Renewable carrying capacity of Ghana from 2000 to 2019.

4.4 Summary

The emergy synthesis indicated that total emergy use increased by 126.53% from 2000 to 2019. The change in total emergy use was attributable to increased import emergy, from 2.90% to 37.47% while Ghana's self-sufficiency capacity decreased from 97.10% to 62.53% in the investigated period. This variation in total emergy utilization categorizes the Ghanaian socioeconomic system as transitioning from high dependence on indigenous resources to a growing reliance on purchased resources to drive economic growth. The proportion of indigenous nonrenewable emergy (N) increased by 75% in the investigated period due to significant government and foreign direct investment in agriculture and extractive industries, boosting the quantity of resources produced. Import emergy surged by 28.27 times, owing to Ghana's progressive diversification of its economy and rising import demand partly driven by multilateral trade agreements in the form of tariff reductions and removal.

Approximately 18% decline in emergy use per person (EC) does not necessarily depict a drop in living standards due to significant rise in economic and industrial activities (reflected by the Empower indicator) observed in the investigated period The rising empower density (ED) trend is indicative of more intensity of economic activities, industrialization, and land usage in Ghana. Furthermore, the observed decrease in emergy yield ratio (EYR) and increasing emergy investment ratio (EIR) indicators imply that Ghana is progressively gaining competitiveness in foreign trade and benefits more from its trading partners. The increasing environmental loading ratio (ELR) trend signals rising environmental stress imposed by purchased inputs. Ghana is challenged with the capacity to optimally utilize its potential indigenous renewable sources, as shown by the present renewability ratio (R=16%). However, this affords the opportunity to make steadfast efforts that promote optimal utilization of renewable resources, particularly solar energy. Ghana's emergy sustainability index (ESI) value is less than 1, categorizing Ghana's socioeconomic system as resource-consuming and low-environmental performance. The present study recommends restructuring Ghana's socioeconomic system to ensure optimal use of its indigenous renewable resources to the largest possible extent while minimizing its nonrenewable resources dependency, ecosystem stress, and the consumption of purchased resources.

The next chapter investigates the effect of expansion of Ghana’s urban areas on socioeconomic metabolism. How does the increasing urban area cause changes in Ghana’s resource consumption?

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CHAPTER V

URBANIZATION AND SOCIOECONOMIC METABOLISM

5.0 Introduction

This chapter investigates the effect of urbanization on Ghana's socioeconomic metabolism. The growth trends of unit emergy consumption of fuels, construction materials, and electricity emergy demand were used as a proxy to determine how the expansion of Ghana's urban areas reflects the dynamic trend of emergy flows that supports its socioeconomic system. The findings indicated that the expansion of Ghana's urban areas partly drives resource consumption, particularly refined fuels, and construction materials.

5.1 Rising Fuel consumption for urban energy demand

Figure 23 shows that unit emergy consumption of fuel (sej/km^2) is positively correlated with increased urban areas. Unit emergy consumption of fuel increased by 80.47% from 3.38E+17seJ in 2000 to 6.10E+17seJ in 2019, while urban areas increased by 139.32% over the 19 years (Table 6). This result is hardly surprising as this is typical of present-day urban centers. It is not difficult to recognize that as the built-up area and urban population rise, so will the demand for fossil fuels for transportation, energy production, cooking, and other purposes. According to literature, increase in fuel and energy consumption is partly linked to increase in household income levels (Masera et al., 2000; Kowsari and Zerriffi, 2011; Mika et. al., 2021, among others). This consensus does not deviate from the Ghanaian scenario. Between 2005/2006 and 2012/2013, Ghana's mean annual household income increased from Gh₵1,217.00 to Gh₵16,645.00 (GSS, 2018). Furthermore, in 2016/2017, the mean annual household income increased to GH₵33,937.00, directly increasing consumption of resources.

Road transport primarily dominates transportation in Ghana. Vehicle ownership has risen substantially over the years because Ghana's mass transportation system is challenged by a myriad of operational inefficiencies that make it inefficient and unappealing to citizens. Ghana's vehicle/population ratio grew by 40%, from 50 vehicles per 1000 persons in 2010 to 70 vehicles per 1000 persons in 2015. Registered vehicles were 1,952,564, with Accra and

Kumasi metropolitan areas (the two most populated urban areas) accounting for 73.47 % of the total. With the growing trend of individual vehicle ownership and informal private transport coupled with the amorphous spatial structure of most Ghanaian cities, there is increasing congestion and unnecessary travel delays on majority of urban roadways. While it is reasonable to argue that the expansion of developments into suburban areas reflects increased mobility in those areas, the bulk of Ghana's urban travel pattern occurs in the city center, which harbors the majority of jobs, market centers, shopping malls, etc. Figure 24 & 25 show the travel pattern in Accra and Kumasi (the largest urban areas in Ghana) with extreme traffic flow into the city center. Most of the developing suburban areas lack transport accessibility, neighborhood and street connectivity.

Adarkwa and Poku-Boansi (2011), Adarkwa (2012) and Bawakyillenuo and Agbelie (2015) argue that the transportation system would become unsustainable unless private travel is discouraged. Increasing the accessibility, efficiency, and management of the public transportation system, particularly in urban Ghana, can substantially increase the usage and patronage of public transport and potentially cut down demand for fuel and the use of individual vehicles.

Table 6 Relations between increased urban areas and socioeconomic metabolism

Index	Value			
	2000	2010	2019	% Diff. 00-19
Urban areas(km^2)	1294.744	1941.7	3098.55	139.32%
Unit Fuel Consumption(seJ/km^2)	3.38E+17	4.45E+17	6.10E+17	80.47%
Unit Construction materials Consumption (seJ/km^2)	1.84E+18	2.04E+18	3.14E+18	70.65%
Unit Electricity Consumption(seJ/km^2)	4.33E+18	3.49E+18	3.66E+18	-15.47%

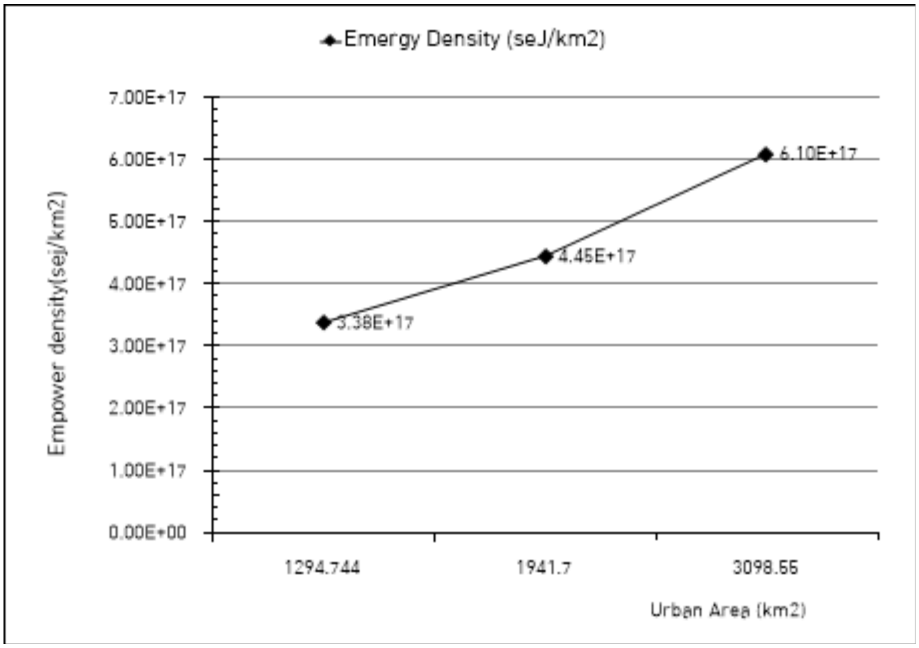

Figure 23. Fuel consumption emergy flow per urban area from 2000 to 2019.

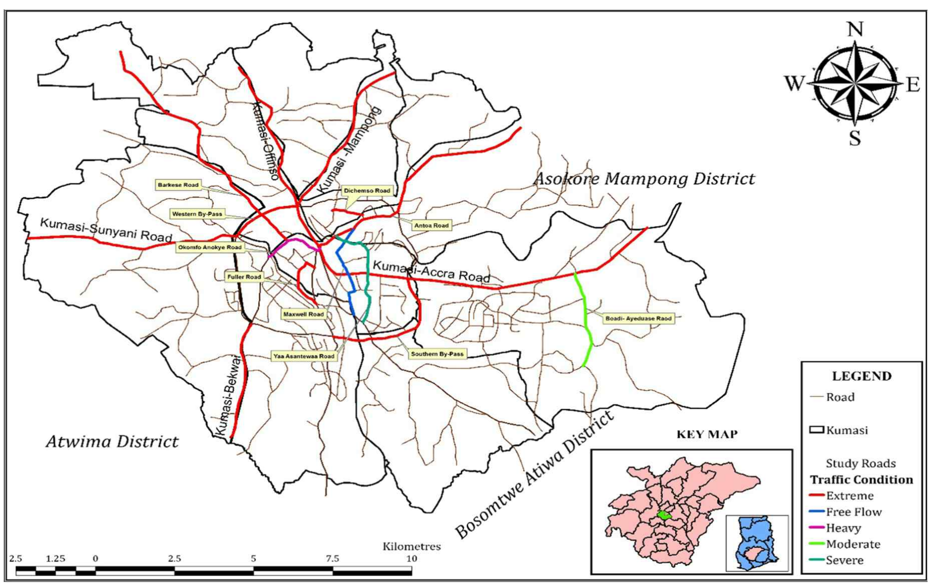

Figure 24. Traffic conditions in Kumasi Metropolitan Area.

Source: Adapted from Poku-Boansi and Adarkwa (2011); Poku-Boansi, M., & Cobbinah, P. B. (2018).

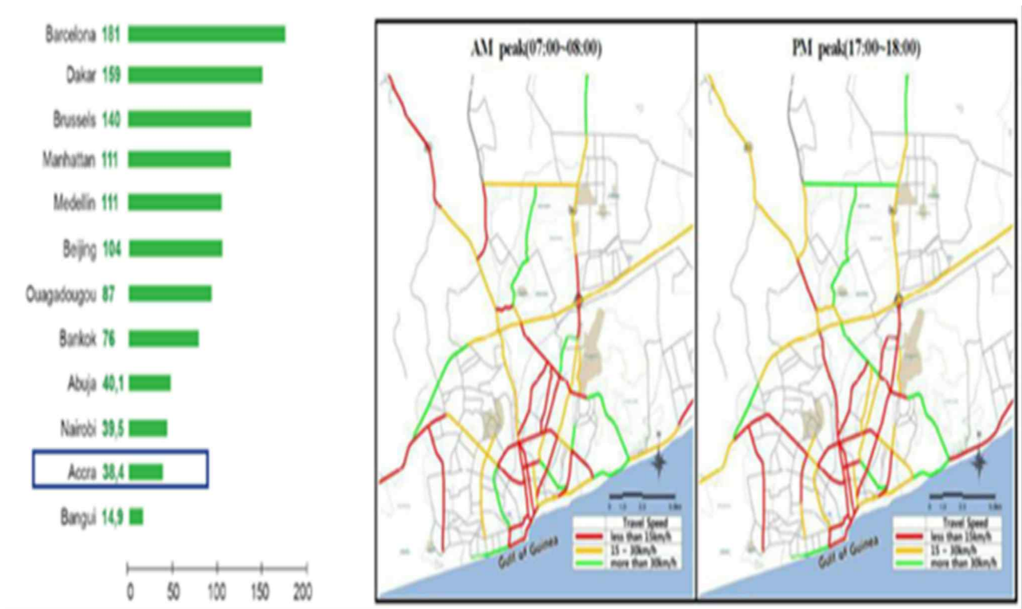

Figure 25. Traffic conditions during peak hours in Greater Accra Metropolitan Area.

Source: Adapted from GAMA Transport Master Plan; SSATP_UTM Final Report, (2018).

5.2 Increasing construction materials demand for urban construction

Similar to the growth behavior of fuels, unit emergy consumption of construction materials strongly indicates increasing volumes of urban construction activities. Unit emergy consumption (sej/km^2) of construction materials grew by (+70.65%) from 1.84E+18seJ in 2000 to 3.14E+18seJ in 2019 (Figure 26). This is attributed to massive infrastructural developments (civil works and real estate) that have been ongoing since 2010, as reflected by the inflow of construction materials emergy which increased substantially between 2010 and 2019, mirroring a quantum leap of 148%. The government flagship programme "One district One factory" implemented in 2017, has substantially increased imports of construction materials considering the fact that as of November 2021, the initiative had 150 factory projects at various stages of construction across the country. Furthermore, over the years the number of construction companies have more than doubled , increasingly dominated by the inflow of foreign companies which has resulted in increase of foreign finished products largely used in civil construction and massive public projects. Also social acceptance of foreign products being of higher quality than domestic products partly drives imports of construction materials observed in this study. Due to the rapid urbanization, Ghana is challenged with a large housing deficit, particularly in urban areas. Ghana Investment Promotion Centre (GIPC, 2006) reported that Ghana requires between 110,000 and 140,000 housing units annually to reduce the country's housing deficit to the bare minimum. ISSER (2013) and Frimpong et al. (2020) reported a housing deficit of 70,000 to 120,000 units, with 30-35 % of the annual estimate being supplied. While the annual housing supply seems to be increasing, the housing deficit remains huge and can potentially impact the emergy inflow of construction materials.

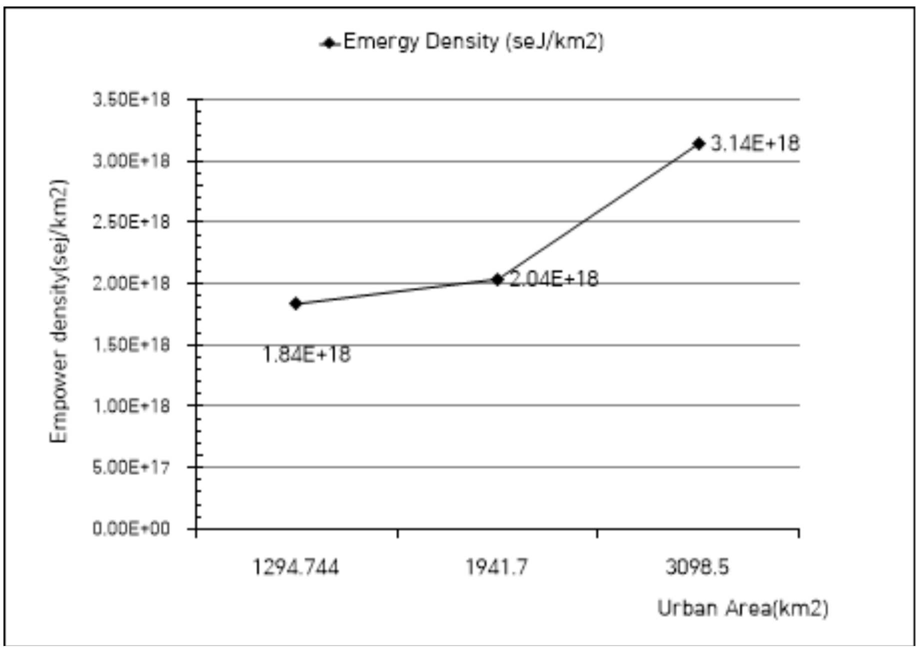

Figure 26. Construction materials emergy flow per urban area from 2000 to 2019.

5.3 Fluctuating increasing trend of urban electricity demand

Unit consumption of electricity provides further insight into the dynamism of Ghana's urban fabric in the investigated period. Unit consumption of electricity shows a fluctuating rising tendency, which differs from the growing trend of built-up areas. Unit emergy consumption of electricity was highest in 2000 (4.33E+18seJ/km^2), plummeted in 2010 (3.49E+18seJ/km^2) before a steady rise in 2019 (3.66E+18seJ/km^2) [Figure 27]. The obvious question is how the emergy unit consumption of electricity observed in this study provides information about Ghana's evolving urban morphology between 2000 and 2019? The sharp decline between 2000 and 2010 can possibly be attributed to the increase in electricity tariffs, which compelled urban residents to become more energy-conscious, and the increase in the use of renewable energies such as biomass (charcoal and wood) as primary energy. Energy Commission of Ghana (2019) reported that the average electricity end-user tariff increased by approximately 41- fold from 0.017Gh₵/kWh in 2000 to 0.716Gh₵/kWh in 2019; in dollar terms US$0.024/kWh in 2000 to US$0.137/kWh in 2019. This increase in electricity tariff influenced consumers' willingness to pay (WTP) for cheaper and alternative sources reflecting the decline in emergy unit consumption of electricity in 2010. Accordingly, Ofosu-Ahenkorah et al. (2008) found that energy consumption surged in 2008, with biomass accounting for around 72 % of primary energy, and electricity and petroleum accounting for the remaining percentages.

However, between 2010 and 2019, emergy unit consumption of electricity in urban Ghana increased by (+4.86%), which could be attributed to (1) an increase in vertical developments (high-rise buildings) for commercial and office purposes, (2) increase in lateral developments. Ghana's urbanization has been dominated by lateral developments (low-rise buildings); however, there has been a growing consensus of vertical developments as optimal land use in the past decade, increasing vertical developments and changing the pattern of skyline of most urban centers in Ghana. Adarkwa (2012) reported that a skyline of five or more storeys dominates most urban centers in Ghana. Accordingly, the demand for electricity for lighting, air conditioning, and operation of office equipment has increased significantly. Energy Commission of Ghana (2019) indicated that the residential electricity consumption rate increased from 29.4% in 2000 to 45.6% in 2019. Additionally, Korenteng (2010) opined that the increase in energy demand is partly attributed to several commercial buildings and office complexes in Accra and Kumasi metropolitan areas.

While renewable energies such as solar energy are gradually gaining attention and patronage from the general public, high expenditure and technical difficulties prevent the masses from depending on renewable energies for their energy needs. In 2015, the National Solar Rooftop Programme was initiated with the goal of reducing peak load on the national grid by 200MW aimed at residential beneficiaries (Appiah, 2016). Because of technical obstacles and expenditure, this Programme is yet to reach its goal. The government and its partners can potentially reduce electricity emergy demand through subsidies to increase patronage of such programmes. Also local production of photovoltaic solar panels can create a local market to reduce the cost of solar panels, create more jobs and increase revenue.

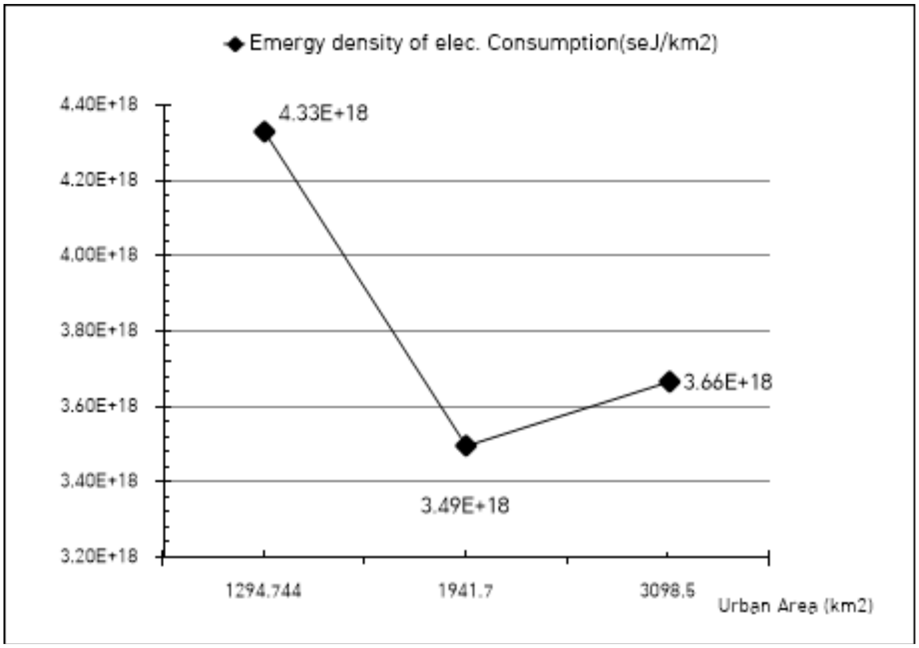

Figure 27. Trend of electricity emergy demand per urban area from 2000 to 2019.

5.4 Summary

This chapter used the growth behavior of the unit consumption of fuels, construction materials, and electricity as a proxy to determine how the expansion of Ghana's urban areas reflects the dynamic trend of emergy flows that supports the country's socioeconomic system. As shown in figures 23 & 26, the growth behavior of both unit consumption curves indicates that no stabilization of emergy inflows of fuel and construction materials was observed, reinforcing the notion that Ghana's urban system is still in the growing stage because growth limits had not been reached in the investigated period. The urban system of Ghana acts as a hub for resource consumption with a growing trend toward more usage of fossil fuel and construction materials from external sources.

Based on the growth tendency observed in this analysis and the fact that Ghana has high fuel and construction materials import-dependency rate, imports of fuel and construction materials would continue to increase, rendering Ghana's urban system fragile and unsustainable in the long run. In tandem with the pursuit of sustainable development, policymakers should reduce imports of construction materials while maintaining construction industry activities through the reuse and recycling of construction materials and the use of less-emergy intensive materials to effectively utilize energy and matter. Policies are required to reduce private vehicle usage in favor of more effective and efficient mass transportation such as; bus rapid transit system to reduce demand for gasoline and other petroleum products. The renewable use to total emergy use(R/U) ratio in 2019 (Table 4) depicts that Ghana runs on approximately 84% of nonrenewables to support the functioning mechanisms of its socioeconomic system. Our human societies are challenged with the inevitable scarcity of nonrenewables which will determine the existence of our societies; therefore, policymakers need to cut down dependence on nonrenewables, especially in the energy sector.

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CHAPTER VI

FINDINGS AND RECOMMENDATIONS

6.0 Introduction

This work assessed the environmental performance and sustainability of Ghana's socioeconomic metabolism from 2000 to 2019 based on Emergy Synthesis. This chapter summarizes the research findings and gives policy implications to achieve sustainable use of indigenous renewable resources while reducing nonrenewable and purchased resources dependency.

6.1 Findings

This study evaluated the major renewable and nonrenewable resource flows supporting Ghana's socioeconomic system from 2000 to 2019 based on emergy synthesis (ES) to; evaluate the trend of resources consumption, sustainability status, and investigate the effect of urbanization on Ghana's socioeconomic metabolism. Based on the emergy synthesis the following findings were made;

1. **Increasing contribution of purchased inputs to total emergy use**

   Total emergy use of Ghana increased by 126.53% from 2000 to 2019. Change in total emergy use was attributable to increased imports with contributions from 2.90% to 37.47%, and self-sufficiency capacity decreased from 97.10% to 62.53% in the study period. This variation in total emergy utilization categorizes the Ghanaian socioeconomic system as transitioning from high dependence on indigenous resources to a growing reliance on purchased resources to drive economic growth. The proportion of indigenous nonrenewable emergy (N) increased by 75% due to significant government and foreign direct investment in agriculture and extractive industries (fossil fuels, metals and minerals), boosting the quantity of resources produced.

2. **Over-liberation of the Ghanaian economy**

   Import emergy surged by 28.27 times, owing to Ghana's progressive diversification of its economy and rising import demand partly driven by multilateral trade agreements in the form of tariff reductions and removal. Ghana received 58% net emergy flow within the study period with manufactured and finished goods and services dominating imports. The observed increasing trend of imports further signals that Ghana’s economic growth is partly dependent on external resources.

3. **Increasing competitiveness in foreign trade**

   The observed decrease in emergy yield ratio (EYR) and increasing emergy investment ratio (EIR) indicators imply that Ghana is progressively gaining competitiveness in foreign trade and benefits more from its trading partners. EIR of Ghana indicates that more purchased resources were required to exploit a unit of indigenous resources, implying gradual diversification of the country’s economy.

4. **Transformation of import emergy imposes environmental stress**

   The increasing environmental loading ratio (ELR) trend does not necessarily depict extreme exploitation of Ghana's indigenous resources by the growing industrial activities, but signals increased investment pressure of purchased resources on the local environment.

5. **Less utilization of renewable sources**

   Ghana is challenged with the capacity to optimally utilize its potential indigenous renewable sources, as shown by the present renewability ratio (R=16%). However, this affords the opportunity to make steadfast efforts to optimally utilize renewable resources, particularly in the energy sector, such as solar energy.

6. **Low-environmental performance**

   The emergy sustainability index (EmSI) value of Ghana is less than 1, categorizing Ghana's socioeconomic system as resource-consuming and low-environmental performance. The verified ESI value in 2019 (0.54) suggests that Ghana is moving further away from being in equilibrium with its natural environment, necessitating a restructuring of industrial and economic activities to reduce dependence on nonrenewable resources and imports.

7. **Urbanization increases resource consumption**

   Additionally, analysis of the effects of expansion of Ghana's urban areas on socioeconomic metabolism indicates that expansion of urban areas partly drives resource consumption, particularly refined fuels and construction materials. Given that the country has significant fuel and construction materials import-dependency, I argue that imports of fuel and construction materials will continue to increase, rendering Ghana's urban system fragile and susceptible to market shocks in the long-term.

6.2 Recommendations

The study recommends restructuring of Ghana's socioeconomic system to depend on indigenous renewable sources to the largest possible extent while minimizing import dependency. Concerned policymakers should implement the following measures;

Renewable energy policy

Ghana needs a renewable energy policy to ensure that bulk of the country's energy production is generated from renewable sources. Ghana has abundant renewable sources (solar, wind, geothermal, among others) but lacks the capacity to utilize its renewable resource base. Ghana's renewable emergy/total emergy use declined from 38.01% to 16.84% within the 19 years period. It is imperative that policies should be geared towards harnessing and promotes the use of renewables to replace the dependency on fossils. Specifically, addressing the technical challenges and lowering costs through government subsidies will encourage participation like the National Solar Rooftop Programme, which can be the first step toward lowering electricity emergy demand. Also, with the increase in high-rise buildings, periodic energy audits must be conducted to know the energy consumption and efficiency of the high-rise buildings since most developments in Ghana fail to incorporate the energy efficiency standards required by building codes and regulations. Enforcing the energy efficiency standards can potentially reduce electricity consumption and propel the country towards sustainable development. Furthermore, the removal of fossil fuel subsidies might limit their imports and usage to enhance patronage of renewable energy sources.

Industrial Restructuring and Upgrading

Based on the emergy synthesis on international exchange, Ghana's import emergy/ export emergy in 2019 was 2.98:1, indicating that import emergy was roughly three times more compared to export emergy; thus, Ghana has a negative trade balance. Manufactured goods primarily dominate Ghana's imports due to inadequate manufacturing industries to process raw materials to meet domestic demand. Therefore, Ghana needs a new trade policy to specialize in producing and exporting final goods to replace the current practice of exporting raw materials and unprocessed products with low added value. The new trade policy must establish an inter-sectoral network between extractive industries and other sectors of the economy to create an internal market and potentially reduce imports. An expanding manufacturing sector consumes more resources while putting further strain on the environment and generating more waste. Hence, policies should be implemented to compel industries to reuse and recycle products while minimizing waste discharge to contribute to the creation of a circular economy. Furthermore, Ghana must improve the domestic production of construction materials such as aluminum, steel, and cement to meet the rising urban construction demand and generate more jobs and revenue.

Promote Public Transport

This study pointed out a rising trend of fuel consumption for urban energy demand due to increase in vehicle ownership and operational inefficiencies of the public transportation system. Concerned policymakers should improve the efficiency of the public transportation system, particularly in urban Ghana, to significantly boost its patronage. Ghana needs Bus Rapid Transit (BRT) systems to ensure cost-effective urban mobility and reduce individual vehicle usage. The operation and accessibility to BRTs will eliminate unnecessary traffic congestion in the urban centers and allow urban dwellers to have access to most jobs within the shortest time of commute. Transport authorities can begin by creating segregated public transport right-of-way to reduce traffic congestion. Congestion pricing and road rents are mechanisms that must be implemented to discourage driving during peak hours and potentially reduce traffic flow in urban centers and major urban arterial roads. Furthermore, establishing appropriate road lanes and safety measures for less-road-intensive vehicles such as bicycles and motorbikes will increase public demand for such vehicles. These measures will potentially cut down the use of individual vehicles and the demand for transportation energy. Furthermore, the government should encourage the use of clean energy in the transportation industry to lessen the strain on the environment. This recommendation will require further emergy analysis to determine whether it can potentially reduce the demand for transportation energy.

6.3 Limitation of Study

Due to the extensive nature of the study, the most pressing challenge was data availability. Inputs such as public service, information, and education emergy were ignored due to data unavailability. The accuracy of the emergy synthesis on Ghana’s urbanization and socioeconomic metabolism could be further increased if institutions provide data on the urban scale. The study used the national scale resource consumption data since information on resource consumption on the urban scale is nonexistent. Nevertheless, the findings of this study provide policymakers with insights and suggestions for policy revision and the formulation of environmentally-conscious policies to achieve sustainable development.

6.4 Recommendations for future research

Future study will explore the following research lines:

1. Simulation of the emergy parameters of this work to project future emergy trends of Ghana's socioeconomic system to inform policy decisions.
2. Future work will apply emergy synthesis to evaluate and compare countries within ECOWAS (Economic Community of West African States) to investigate the impact of trade among member countries on their environmental performance.
3. To investigate the relationship between the continental location, development status of socioeconomic systems and their environmental performance. Access to renewable and nonrenewable resources is arguably restricted by the continental location of a socioeconomic system that significantly dictates and characterizes self-sufficiency and long-term sustainability. However, regardless of the benefit of continental location, domestic economic productivity and resource utilization efficiency may impact the quantity of emergy invested to circulate commodities, currencies, services, and the performance of a socioeconomic system. Understanding the correlation between continental location and development level impact on the performance of socioeconomic systems is required.

Appendix A

Footnotes to Table 3 &Table 4

Renewable Resources (R)

1. **Solar radiation**

   Annual energy= (Avg. Total annual insolation J/yr) (Area)(1-albedo)(Odum, 1996; Srinivasan & Moe (2015).

   Total area of GHANA=2.30E+04 sq.km^2; 2.3E+11 m^2

   Average daily solar insolation=412.82MJm^{-2}day^{-1} (Asilevi et al., 2019).

   Albedo =0.28

Solar radiation	2019	2010	2000
Energy in Joules(J)	2.50E+22	2.50E+22	2.50E+22

2. **Rain, chemical potential energy**

   Annual energy= (in/yr)(area)(0.0254m/in)(1E6g/m^3)(4.94 J/g)(1-runoff)

   Total area of GHANA=2.30E+ 11m^2

   Runoff coefficient= (1-0.6) =0.4

   Gibbs free energy J/g= 4.94(Odum, 1996)

   Density of rainwater=1.00E+06g/m^3

Rain, chemical potential energy	2019	2010	2000
Raw data(mm)	1169.20	1227.1	1187.50
Energy in Joules(J)	5.42E+17	5.58E+17	5.31E+17

3. **Rain geo-potential energy**

   Geo-potential energy= area)(rainfall)(% runoff))(*1000kg/m^3) (avg elevation)(gravity)

   Total area of GHANA=2.30E+ 11m^2

   Mean elevation=190m (https://www.indexmundi.com/ghana/elevation_extremes.html)

   Rainfall=1.16m

   Runoff rate = 0.20 % (percent, given as a decimal) (Odum, 1996)

   Assumption on gravity= 9.81 ms-2

   Geo-potential energy=9.94E+16 J

Rain, geo- potential energy	2019	2010	2000
Raw data(mm)	1169.20	1227.1	1187.50
Energy in Joules(J)	9.94E+16	1.03E+17	1.016E+17

4. **Wind energy**

Annual energy= (area)(air density)(drag coefficient)(velocity^3)(sec/yr)

Area=2.30E+11m^2 Density of air=1.30E+00kg/m^3 Land wind velocity=2.6E+00m/s, Geostrophic wind=8.33E+00m/s; Drag Coefficient=1.00E-03 (Srinivasan & Moe (2015). Sec/yr=3.14E+07

Wind energy	2019	2010	2000
Energy in Joules(J)	2.03E+17	2.03E+17	2.03E+17

5. **Deep Heat**

Area=2.30E+11m^2

Heat flow=4.20E+01mWm^2/yr(Mwambo et al.,2020)

Heat flow per unit area= 1.32E+06J/m^2/yr

Deep heat=3.036e+17 J

Deep Heat	2019	2010	2000
Heat Flow (Wm^2/yr.)	4.20E+01	4.20E+01	4.20E+01
Energy in Joules(J)	3.036E+17	3.036E+17	3.036E+17

6. **Tidal Energy**

Energy (J) = (shelf)(0.5)(tides/y)(mean tidal range)^2 (density of seawater)(gravity)

Cont. Shelf Area = 6.35E+10 m^2

Average Tide Range = 1m (http://www.tidetablechart.com/tides/region/Ghana

Density of sea water = 1.03E+03 kg/m3

Tides/year = 7.30E+02 (estm. of 2 tides/day in 365 days)

Tidal energy (J)= (____m2)*(0.5)*(____/yr)*(____m) 2*(_____kg/m3) *(9.8m/s2)

Tidal Energy	2019	2010	2000
Energy in Joules(J)	2.34E+17 J	2.34E+17 J	2.34E+17 J

7. **Topsoil loss, erosion**

Net topsoil loss= (Area)(erosion rate)

Area= 2.30E+11m^2

Erosion rate= 1.29E+01$g/m^2/yr$ (Badmos et al.,;Mwambo et al.,2020)

Organic matter in topsoil used up= (Total mass of eroded topsoil)(% organic)

Average % of organic matter in soil=0.05 (Tabo, 2008)

Energy content organic=5.40kcal/g (4186J/kcal)

Topsoil Loss, erosion	2019	2010	2000
Energy in Joules(J)	3.35E+15	3.35E+15	3.35E+15

Indigenous Renewable Energy (N)

8. Hydroelectricity

Hydroelectricity	2019	2010	2000
Raw data(GWh)	7,252	6,995	6,610
Energy in Joules(J)	2.610E+16	2.518E+16	2.37E+16

Source: www.energycom.gov.gh

9. Main food crops excluding industrial crops

Main Food Crop	2019 (Qty. in Metric tons)	2010 (Qty. in metric tons)	2000 (Qty. in metric tons)
Root & Tubers	32,408,719.00	20,939.526.00	13184795.00
Rice	925,000.00	491,603.00	248700.00
Soybean	1,767,000.00	146,000.00	-
Groundnut	521,000.00	530,887.00	209,000.00
Cowpea	237,000.00	219,257.44	-
Green beans	26,095.00	21,241.00	20,000.00
Total quantity (g/yr.)	**3.58E+13**	**2.23E+13**	**1.37E+13**

Source: FAOSTAT | Food and Agriculture Organization

10. Cash Crops

Cash crops	2019(Qty. in	2010(Qty. in metric	2000(Qty. in metric tons)

	metric tons)	tons)	
Cocoa	811,747	632,037.00	436,600.00
Coffee	600	1200.00	1956.00
Oil crops	830,334.00	3,022,069.00	1,686,429.00
Sugarcane	153,670	145,000.00	140,000.00
Cashew	85,962	32,638.00	9,138.00
Rubber	30,500	20,150.00	8,700.00
Cotton	12,428	12,000.00	35,503.00
Total quantity (g/yr.)	**1.93E+12 g/yr.**	**3.87E+12**	**2.32E+12**

Source: FAOSTAT | Food and Agriculture Organization

11. Fruits and Vegetables:

Fruits & Vegetables	2019	2010	2000
Raw data in g/year	1.73E+12	5.52e+12	3.02E+12

Source: FAOSTAT | Food and Agriculture Organization

12. Cereals and derivatives:

Cereals & Derivatives	2019	2010	2000
Raw data in g/year	4.22E+12	2.91E+12	1.72E+12

Source: FAOSTAT | Food and Agriculture Organization

13. Livestock and Poultry Products;

Energy (J) = (Total production) (energy content)

Energy (J) = (1.75E+06MT)*(1E+06 g/MT) *(5.0 KCal/g)*(4186 J/KCal)

	2019	2010	2000
Livestock & Poultry Products			
Raw data in Metric tons	1.75E+06	1.19E+06	7.67E+05
Energy in Joules(J)	3.66E+16	2.50E+16	1.61E+16

Source: FAOSTAT | Food and Agriculture Organization

14. Fisheries production:

Energy (J) = (Total production)(energy content

Energy (J) = (4.60E+05 MT)*(1E+06 g/MT)*(5.0 KCal/g)*(4186 J/KCal) =

	2019	2010	2000

Raw data in Metric tons	4.60E+05	3.50E+05	4.50E+05
Energy in Joules(J)	9.6278e+15	7.32E+15	9.42E+15

Source: FAOSTAT | Food and Agriculture Organization

15. Biomass production

(Raw data)*(3.6kcal/g)*(4186 J/kcal)

Biomass Production	2019	2010	2000
Raw data(Ktoe)	4,218.5	3,207.0	3890.6
Energy in Joules(J)	6.35E+16	4.84E+16	5.86E+16

Source: www.energycom.gov.gh

16. Timber harvest

Energy (J) = (Total production) (energy content) (80% humidity)

Energy (J) = (Raw data) (0.5E+06 g/m3) (80%) (3.6 kcal/g)(4186 J/kcal)

Timber harvest	2019	2010	2000
Raw data(cubic meters)	149,924.9m^3	3.95E+07m^3	2.75E+07m^3
Energy in Joules(J)	9.04E+14	2.38E+17	1.70E+17

17. Major Minerals Production

Major Minerals(g/yr) Production	2019	2010	2000
Gold	1.30E+08	8.42E+07	6.56E+07
Diamond	6.76E+03	6.17E+04	1.25E+05
Bauxite	1.12E+12	5.122E+11	5.04E+11
Manganese	5.83E+12	1.194E+12	6.38E+11

Source: Ghana Chamber of Mines 2019 Industry Statistics & Data

18. Metals

Metals	2019	2010	2000

Aluminum (g/yr.)	4.32E+10	3.94E+10	1.55E+11
Steel (g/yr.)	2.50E+10	2.50E+10	-

19. Fuels

Fuel	2019	2010	2000
Crude oil	4.14E+17	-	-
Natural gas	6.23E+14	-	-

No data for 2010 and 2000 since Ghana had not begun to exploit its oil reserves.

Source: National energy statistics 2000-2019; www.energycom.gov.gh

IMPORTS

20. Refined Fuel:

Refined Fuel	2019(Qty. in Ktoe)	2010(Qty. in Ktoe)	2000(Qty. in Ktoe)
LPG	275.2(1.15E+15J)	148.00(6.192E+15J)	35.4(1.48E+14J)
Gasoline	1,265.00(5.29E+15J)	570.10(2.38E+15J)	387.00(1.619E+15J)
Gasoil	1,7416.00(7.29E+14J)	871.7(3.65E+15J)	363.2(1.520E+15J)
ATK	180.7(7.56E+140J)	-	-

Source: National energy statistics 2000-2019; www.energycom.gov.gh

21. Electricity

Hydroelectricity	2019	2010	2000
Raw data(GWh)	127.00	106.00	864.00
Energy in Joules(J)	4.57E+14	3.816E+14	3.11E+15

Source: National energy statistics 2000-2019; www.energycom.gov.gh

22. Metals imports (main commodities)

Metals	2019	2010	2000
Aluminum (g/yr.)	3.99E+10	2.57E+10	3.79E+09
Steel & Iron (g/yr.)	7.72E+10	5.91E+10	2.64E+10
Copper& articles (g/yr.)	5.73E+09	1.90E+10	2.20E+09
Zinc (g/yr.)	7.41E+07	6.18E+07	4.42E+08

23. Fertilizers & Pesticides

    2019 Total Fertilizer imports= 2.86E+05 tons

    Pesticides= 68588.034 tons

    2010: Fertilizers=311,387,321kg; 3.11E+11g

    Pesticides= 50368.585tonnes; 5.12E+10g

    2000: Fertilizers= 3.43E+10g

    Pesticides= 10413.037tonnes; 1.06E+10g

    Source:https://knoema.com/atlas/Ghana/topics/Agriculture/Fertilizers-Import-Quantity-in-Nutrients/Urea-import

    http://www.fao.org/faostat/en/#data/RFN

24. Chemicals(Organic and Inorganic)=

    2019 7.03E+07 kg; 7.03E+10 g, 2010: 8,351,643kg; 8.48E+12g, 2000:)= 3,145,624kg; 3.20E+12g

25. Plastic and synthetic Rubber

Plastic & Synthetic Rubber	2019	2010	2000
Total quantity in g/yr.	3.04E+11	1.34E+10	3.95E+09

    Source: http://www.fao.org/faostat/en/#data/RFN

26. Machinery and transport equipment=

    2019: $ 1.13E+07, 2010: =$9.86E+06 , 2000: =$ 2.56E+06

27. Finished Materials(paper, textiles, glass and other)

    Source: (http://www.fao.org/faostat/en/#data/RFN

28. Food and Agricultural products

    2019: 3.24e+12 g, 2010: 1.98E+12g, 2000: 9.76E+11g

    (http://www.fao.org/faostat/en/#data/RFN)

29. Livestock, Meat and Fish=

    2019: 228516 MT= 2.29E+11g,

    2010: $8,152,000.00,

    2000: $9,802,000.00

30. **Construction materials**

Bricks, tiles, ceramic goods or crushed stones

		UEV	Reference	Emergy	
2000	89900000	4.93E+12	Buranakarn V., 1998.	4.43E+20	sej/g
2010	26400000	4.93E+12		1.30E+20	sej/g
2019	126000000	4.93E+12		6.21E+20	sej/g

Pebbles, gravel, broken , crushed stones(for road metalling, railway etc)

		UEVs	Reference	Emergy	
2000		1.68E+09	Odum, 2000		
2010	61040	1.68E+09		1.03E+14	sej/$
2019	304459	1.68E+09		5.11E+14	sej/$

Cement Production

		UEVs	Reference	Emergy	
2000	1.1E+12	1.73E+09	Brown and Arding, 1991)	1.90E+21	sej/g
2010	2.17E+12	1.73E+09		3.75E+21	sej/g
2019	5.22E+12	1.73E+09		9.03E+21	sej/g

Wood and articles of wood

		UEVs	Reference	
2000	3.45E+09	6.79E+08	Odum, 1996	2.34E+18
2010	2.30E+10	6.79E+08		1.56E+19
2019	4.40E+10	6.79E+08		2.99E+19

Other construction materials	2019(Qty. in g/yr.)	2010(Qty. in g/yr.)	2000(Qty. in g/yr.)
Paper	3.16E+11	8.20E+10	4.28E+10
Textiles	1.06E+10	1.40E+10	8.60E+09
Glass	5.45E+10	5.02E+10	2.60E+10

31. **Imported services**

2019: $ 1.0541E+11, 2010: $3.0E+09, 2000: =$ 5.84E+08

The imported services comprise such things as transport, financial and insurance services.

https://wits.worldbank.org

32. **Tourism**

2019: $1.49E+09, 2010: $7.06E+0 , 2000: $3.57E+08

https://knoema.com/atlas/Ghana/Tourism-receipts

EXPORTS

33.

Item	2019(Qty. in grams)	2010(Qty. in grams)	2000(Qty. in grams)
Food &Agric. products	1.98E+12	6.15e+11	5.62E+11g
Livestock, meat and fish	7.00E+10	$ 3.0E+04	2.56E+05

(http://www.fao.org/faostat/en/#data/RFN)

34.

Refined Fuel	2019(Qty. in Ktoe)	2010(Qty. in Ktoe)	2000(Qty. in Ktoe)
LPG	0.8(3.35E+12J)	0.0(0.00E+00J)	6.2(2.60E+13J)
Gasoline	33.2(4.91E+14J)	9.9(4.41E+13J)	0.0
Gasoil	117.4(4.91E+14J)	290.9(1.22E+15J)	0.6(2.51E+12J)
ATK	208.6(8.73E+14J)	93.6(4.31E+14J)	3.95E+14J)

35. Metals(2019)

Metal type	Quantity in Kilograms	Quantity in grams
Steel and Iron	1.78E+06	1.78E+09
Copper	2.63E+06	2.63E+09
Zinc	1.94E+06	1.94E+09
Aluminum	5.59E+07	5.59E+10

2010

Metal type	Quantity in Kilograms	Quantity in grams
Steel and Iron	2.61E+06	2.61E+09
Copper	7.69E+04	7.70E+07

Zinc	3.40E+04	3.40E+07
Aluminum	3.48E+07	3.48E+10

2000

Metal type	Quantity in Kilograms	Quantity in grams
Steel and Iron	7.19E+06	7.19E+09
Copper	1.68E+06	1.70E+09
Zinc	8.74E+04	8.74E+07
Aluminum	1.21E+08	1.21E+11

36. Minerals

2019

Gold= 1.33E+08 g Diamond= 33789.19carats; 6.76E+03g

Bauxite= 1,100,000MT; 1.1e+12g Manganese= 5,500,000MT ; 5.5e+12 g

(Ghana Chamber of Mines 2019 Industry Statistics & Data)

(https://www.theglobaleconomy.com/Ghana/diamond_exports_carats/

Minerals (2010)

Assumption: all production for both gold and diamond are exported

Gold= 2,970,080 ounces; 8.42E+07g

Diamond=308679 Carats; 6.17E+04 g

Bauxite= 500,000.00 MT; 5.00E+11g

Manganese= 1,100,000.00MT ; 1.10E+12g

(Ghana Chamber of Mines 2019 Industry Statistics & Data)

(https://www.theglobaleconomy.com/Ghana/diamond_exports_carats/

https://www.macrotrends.net/1333/historical-gold-prices-100-year-chart

Minerals (2000)

Assumption: all production for both gold and diamond are exported

Gold= 2,315,000.00 ounces; 6.56E+07g

Diamond=627,000 Carats; 1.25E+05g

Bauxite= 300,000.00MT ; 3.0E+11g

Manganese= 600,000.00 MT; 6.0E+11g

(Ghana Chamber of Mines 2019 Industry Statistics & Data) (https://www.theglobaleconomy.com/Ghana/diamond_exports_carats/

37. Timber harvest

2019: 300,455m^3

Energy(J)= (Total production)(energy content)(80% humidity)

Energy(J) = (300,455m3)(0.5E+06 g/m3)(80%)(3.6 kcal/g)(4186 J/kcal)=1.81E+15J

2010 : 5.45E+05 m3 (FAOSTAT, 2010)

Energy(J)= (Total production)(energy content)(80% humidity)

Energy(J) = (5.45E+05m3)(0.5E+06 g/m3)(80%)(3.6 kcal/g)(4186 J/kcal)=3.30E+15J

2000: 4.01E+05m^3 (FAOSTAT,2000)

Energy(J)= (Total production)(energy content)(80% humidity)

Energy(J) = (4.01E+05m3)(0.5E+06 g/m3)(80%)(3.6 kcal/g)(4186 J/kcal)=2.42E+15J

38. Cash crops

Cash crops	2019(Qty. in grams)	2010	2000
Cocoa	9.02E+11	3.16E+11	4.04e+11
Coffee	2.22E+09	1.73E+09	5.44E+09
Oil crops	1.39E+11	5.75E+10	1.35E+10
Sugarcane	5.38E+07	8.30E+10	3.64E+09
Cashew	2.77E+11	3.35E+10	3.63E+10
Rubber	5.18E+10	7.62E+09	8.22E+09
Cotton	1.51E+09	6.15E+08	2.04E+10
Shea nuts	2.5E+10	2.38E+10	3.60E+10
Total quantity	1.37e+12	5.24E+11	5.28E+11

http://www.fao.org/faostat/en/#data/RFN

39. Electricity exports

2019: 1,430 GWh, National energy statistics 2000-2019; www.energycom.gov.gh

Total quantity in joules= 5.148E+15 J

2010

1,036 GWh National energy statistics 2000-2019; www.energycom.gov.gh

Total quantity in joules= 3.73E+15 J

2000

392 GWh National energy statistics 2000-2019;

Total quantity in joules= 1.41E+15 J

www.energycom.gov.gh

40. Finished materials

2019

Item type	Quantity in kilogram	Quantity in grams
Fertilizer	6.06E+06	6.06E+09
Plastics	9.64E+05	9.64E+08
Textiles	5.31E+04	5.31E+07
Paper	2.67E+06	2.67E+09
Glass	1.06E+06	1.06E+09

2010

Item type	Quantity in kilogram	Quantity in grams
Fertilizer	1.41E+07	1.41E+10
Plastics	4.31E+06	4.31E+09
Textiles	6.38E+05	6.38E+08
Paper	2.31E+05	2.31E+08
Glass	1.51E+06	1.51E+09

2000

Item type	Quantity in kilogram	Quantity in grams
Fertilizer	6.34E+05	6.34E+08
Plastics	1.81E+05	1.81E+08
Textiles	4.31E+05	4.31E+08
Paper	1.77E+05	1.77E+08
Glass	1.38E+05	1.38E+08

41. Chemicals(Organic and inorganic chemicals)

2019: 6.98E+05 kg; 6.98E+08 g

2010: 8.25E+05kg; 8.25E+08g

h2000: 1.13E+04kg; 1.13E+07g

42. Services in exports

2019: $ 8.75E+09 ; 2010: $1.48E+09 ; 2000: $ 5.04E+08 (Bank of Ghana Database)

WASTE

43. Estimation of Solid waste and Construction waste based on figures reported by Miezah et al. (2015).

Solid waste: Biodegradable waste (organic and papers)=0.318kg/person/day

Construction waste: metals, glass, textiles, rubber & leather= 0.096kg/person/day

Total waste= (Waste generated in the year)(population)

Waste	2019	2010	2000
Solid waste	3.53E+12	2.90E+12	2.24E+12
Construction waste	1.07E+12	8.64E+11	6.76E+11

44. GDP and Population of Ghana

ITEM	2019	2010	2000
GDP of Ghana	$6.70E+10	3.22E+10	4.98E+09
Population	3.04E+07	2.46E+07	1.09E+07

국문요약

가나는 사하라 사막 이남의 아프리카 경제에서 가장 빠르게 성장하는 국가 중 하나로 수출 상품의 가격 인상과 자원 추출 증가에 기인한다. GDP 대비 천연 자원 임대료가 같은 기간 동안 두 배 이상 증가했지만 근본적인 문제는 천연 자원에 단단히 고정된 이 거시경제적 추진력과 빈곤 감소가 얼마나 오래 지속되느냐는 것이다? 여러 경제 평가 및 지표가 자원 생성에 필요한 무료 환경 작업을 설명하지 못하기 때문에 가나의 경제 성장에 대한 위협이 완전히 이해되지 않았다. 에머지 (Emergy) 방법론은 공통 측정 단위를 사용하여 에너지, 자재, 인적 서비스, 정보 및 통화 흐름을 직접 비교할 수 있는 가장 포괄적인 자원 회계 기법이다. 이 연구는 2000년부터, 2010년, 2019년까지 가나의 자원소비 및 지속가능성 동향을 평가하기 위해 "emergy" 방법론을 사용하였다. 또한 가나의 급속한 도시화로 자원소비와 국가의 경관에 상당한 영향을 미치고 있다는 점을 고려할 때, 이 연구는 또한 도시화가 자원 소비에 미치는 영향을 조사할 것이다. 연구의 목적은 다음과 같습니다; 1) 2000년부터, 2010년, 2019년까지 가나의 사회경제 시스템에 대한 환경 성과 평가를 수행한다. 2) 가나의 지속 가능성 상태를 측정하기 위해 에머지(Emergy) 기반 성과 지수를 계산한다. 3) 가나의 확장된 도시 지역이 자원 소비에 미치는 영향을 조사한다.

이 연구 결과에 따르면 총 에머지 사용에 대한 구매 수입품의 기여도가 증가했다. 총 에머지 사용량은 2000년부터 2019년까지 126% 증가했다. 총 에머지 사용량에 대한 수입품의 기여도는 2.90%에서 37.47%로 증가한 반면에 가나의 자급률은 97.10%에서 62.53%로 감소했다. 총 에머지 활용의 이러한 변화는 가나의 사회경제 시스템을 토착 자원에 대한 높은 의존도에서 경제성장을 주도하기 위해 구매한 자원에 대한 의존도를 높이는 것으로 전환하는 것으로 분류하다. 재생 불가능한 토착 에머지(N)의 비율은 농업 및 추출 산업(화석 연료, 금속 및 광물)에 대한 상당한 정부 및 외국인 직접 투자로 인해 75% 증가하여 생산된 자원의 양을 늘렸다. 수입 에머지는 가나의 점진적인 경제 다각화와 관세 인하 및 철폐 형태의 다자간 무역 협정에 따른 수입 수요 증가로 인해 28.27배 급증했다. 관찰된 수입품 증가 추세는 가나의 경제 성장이 부분적으로 외부 자원에 의존한다는 밝혔다. EYR(emergy yield ratio)의 감소와 (emergy investment ratio) EIR 지표의 증가는 가나가 대외 무역에서 점진적으로 경쟁력을 확보하고 있으며 교역 파트너로부터 더 많은 혜택을 받고 있음을 의미한다. 증가하는 (environmental loading ratio) ELR 추세는 구매한 자원에 의해 부과되는 환경 스트레스의 증가를 나타내며 반드시 토착 자원의 과잉 착취는 아니다. 가나의 Emergy Sustainability Index(EmSI)은 1보다 작으며 가나의 사회경제 시스템은 자원을 소비하고 낮은 지속 가능성이다. 또한, 증가하는 도시 지역은 부분적으로 자원 소비, 특히 정제된 연료 및 건축 자재를 유발한다.

이 연구는 가나의 에너지 생산의 대부분이 재생 가능 자원에서 생성되도록 재생 가능 에너지 정책을 시행할 것을 권장한다. 또한 가나는 내부 시장을 창출하고 잠재적으로 수입을 줄이기 위해 채굴 산업과 경제의 다른 부문 간의 부문 간 네트워크를 구축하기 위한 새로운 무역 정책이 필요하다. 마지막으로 이 연구는 비용 효율적인 도시 이동성을 보장하고 교통 혼잡을 줄이며 개별 차량 사용을 줄여 잠재적으로 연료 수입을 최소화하기 위해 BRT(Bus Rapid Transit) 시스템의 구현을 권장한다.

주요어: 에머지; 사회경제적 대사; 지속 가능성; 가나