Constructing a SDG 7 Composite Index: A study on the Sustainability Performance of Ghana's Energy System

by

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Abstract: The purpose of this thesis is to examine sustainability trends in Ghana's energy system. This is done through the construction of a composite index, which is suggested as a more proper way to measure progress towards achieving Sustainable Developing Goal 7. The results imply that Ghana's energy system has become more sustainable in social terms, such as energy accessibility and security, but less sustainable in terms of increased usage of non-renewable energy sources and higher emissions. This indicate that Ghana has not been able to leapfrog to sustainability, and that developing countries face a sustainability dilemma when it comes to energy.

Master's Thesis EKHMS35 (15 credits ECTS)

June 2023

Supervisor: Erik Green

Examinator: Prince Aboagye

Word Count: 18 852

Acknowledgements

The paper *A novel Sustainable Development Goal 7 composite index as the paradigm for energy sustainability assessment: A case study from Europe* (2022) has served as an inspiration for this thesis and an introduction on composite index-construction. A special thank you is therefore at hand to Rajvikram Madurai Elavarasan, Rishi Pugazhendhi, Muhammed Irfan, Lucian Mihet-Popa, Pietro Elia Campana and Irfan Ahmad Khan, the authors of this work.

Further, I would like to thank my supervisor Erik Green, whose input and support has been of utter importance in the making of this thesis. Finally, I would like to thank everyone at Lund University for five developing, eventful and learning years, which now come to an end with this thesis.

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List of Abbreviations

AHP	Analytic Hierarchy Process
CI	Carbon Intensity-indicator
CL	Clean Energy-indicator
EA	Energy Accessibility-indicator
EDP	Energy Diversification Parameter
EI	Energy Intensity-indicator
EIA	Energy Information Administration of the United States
ES	Energy Security-indicator
GHG	Greenhouse Gases
GWh	Giga-watt hours
GJ	Giga-joules
IR	Industrial Revolution
Ktoe	Kilo tons of oil equivalent
KWh	Kilo-watt hours
MJ	Mega-joules
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
TJ	Tera-joules
TFEC	Total Final Energy Consumption
TPES	Total Primary Energy Supply
TWh	Terra Watt Hours
UN	United Nations
UNEP	United Nations Environment Programme

1. Introduction

Humanity face challenges related to energy and sustainability. On the one hand, the energy sector is the largest contributor to climate change, as it is accountable for a vast majority of global emissions (Ritchie et al., 2023a; UNDP, 2023a). On the other, energy access is a recognised enabler to growth and development at a societal level and higher standards of living at the individual level (Ritchie et al., 2023b; Stern, 2011; UN, 2021; UNEP, 2023). The energy-related sustainability challenges are therefore complex, containing environmental, social and economic elements (Grübler, 2012).

The seventh Sustainable Development Goal (SDG) proclaim that by the year 2030 we shall "*[e]nsure access to affordable, reliable, sustainable and modern energy for all*" (UNEP, 2023). To achieve this, the goal provides countries with targets to work towards and indicators to measure their progress (Ritchie et al., 2018). Madurai Elavarasan et al. (2022) criticise these targets and indicators. The authors claim that important sustainability aspects – such as emissions and security – are not taken into account. Due to this, Madurai Elavarasan et al. (2022) propose a novel SDG 7 composite index, which they claim evaluate the sustainability of energy systems more properly.

Inspired by Madurai Elavarasan et al.'s (2022) work, I will in this thesis construct a SDG 7 composite index for Ghana over the period 2000-2019. My aim is to create a composite index that can identify trends. In Madurai Elavarasan et al.'s (2022) composite index, only one point in time is considered, i.e. the year of 2018. In such a research setting, it is not possible to identify over-time trends. When examining aspects of sustainable development, trends can be used to evaluate if the development is going in a desirable direction or not, and even make projections about the future.

Examining trends could assist in creating and implementing appropriate policies, to further generate development in a more sustainable direction. Given all this, when interested in sustainable development, it is arguably more relevant to examine trends and not just specific points in time. This motivates examining data over as much time as possible, which resulted in the time-period considered by this thesis.

Further, the choice of Ghana as case study is based on multiple factors. For one, Ghana is a developing country on a development streak, which became a lower-middle income country in 2011 (World Bank, 2021). Further, the country started to extensively extract from new oil and gas resources during the 2010's (Fulwood, 2021). Economic development has historically been linked to higher energy usage and increased greenhouse gas (GHG) emissions (Friedrich & Damassa, 2014; Smil, 2004). This, along with the new extraction of fossil fuels reservoirs, could imply that Ghana's system has become less sustainable over the considered period.

However, there are discussions about developing countries adopting learnings from currently developed countries and chose more sustainable development paths from the start. In that sense, there are theories of developing countries 'leapfrogging' to more sustainable practices directly, instead of following the same, unsustainable practices as currently developed countries (Goldemberg, 1998). Hydropower has been used extensively throughout Ghana's modern history (Acheampong et al., 2019), and there are possibilities of expanding other renewable energy sources in the country (Adaramola et al., 2014; Obeng & Evers, 2010). Therefore, there arguably exists some implications that Ghana could skip further fossil fuel dependence, and leapfrog to sustainable practices directly.

Considering all that is mentioned above, it is of importance to evaluate what really is the case – has Ghana's energy system become less sustainable, or has it been able to leapfrog? There are mainly four contributions from this research. First, it could present valuable learnings for other countries who are yet to develop and/or discover major sources of fossil fuels. Second, the research could generate findings that make it possible to a better understand of the relationship between energy, development and sustainability. Third, it can contribute to the field of sustainable development measurement, by generating a SDG 7 composite index that considers sustainability performance over time. Fourth, there is to my knowledge no other paper that has developed a composite index related to SDG 7 achievement for Ghana, which would be the final contribution of this paper.

1.1. Research Statement

The purpose of this thesis is to examine how sustainable Ghana's energy system is over time. To fulfil this purpose, this thesis aims to answer the following question:

"*Has Ghana's energy system become more or less sustainable in the period 2000-2019?*"

To answer the above question, a composite index is constructed, inspired by the index from Madurai Elavarasan et al.'s (2022) work. In the construction of the index, I collect, normalize, weight and aggregate data related to sustainability aspects of Ghana's energy usage and generation. For normalization, a min-max method is used, while weights were determined using the Analytic Hierarchy Process (AHP). The sustainability aspects that are included in the composite index are related to energy accessibility, cleanliness, security as well as intensities in terms of energy and CO_2 emissions.

1.2. Thesis Structure

The thesis is structured in the following way; after this introduction, Section 2 present some more thorough background information on the energy issue, SDG 7 as well as the case of this thesis – i.e. the country of Ghana. Section 3 is a literature review, which discusses literature on the relationship between energy and development, as well as findings from the African energy sector.

After that, Section 4 describes the empirical strategy of this thesis, while Section 5 cover aspects related to data. The results are found in Section 6, while Section 7 discusses these. Section 8 presents the conclusion and is then followed by a List of References and an Appendix.

2. *Background*

This section describes two essential pillars for the work of this thesis. The first is the seventh SDG, and the second is the country of Ghana. The section starts with an overview of SDG 7, to then present some of its critiques. After that, I briefly present some background information on the country of Ghana, with focus on aspects such as economy and development. The section is then finalized by examining Ghana's usage of energy and electricity.

2.1. Sustainable Development Goal 7

2.1.1. An Overview

In 2015, the member states of the United Nations (UN) agreed on 17 goals related to sustainable development (UNDP, 2023b; WHO, 2023). The aim of these goals are "... to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity." (UNDP, 2023b). These are commonly known as the SDGs, the Global Goals (UNDP, 2023b) or Agenda 2030 (UN, 2023a). Between the goals there are 169 targets and 232 indicators to monitor the achievement of these (Ritchie et al., 2018).

According to the United Nations Environment Programme (UNEP), human usage of energy is one of the main contributors to climate change. However, energy is also considered to be a driver and enabler of economic development (UNEP, 2023). Energy is therefore related to environmental, social and economic aspects of sustainability (Grübler, 2012), and is arguably relevant for multiple SDGs. An example is SDG number 8 – Decent work and Economic Growth (UN, 2023a), as energy is an essential input is most productions (Rosen, 2009). Another example is SDG number 13 - Climate action (UN, 2023a), due to driving role the energy sector has in climate change (UNEP, 2023).

Among the SDGs, number 7 is fully devoted to energy, and is formulated as follows – 'Ensure access to affordable, reliable, sustainable and modern energy for all' (UNEP, 2023). The goal has five targets and six indicators (UNEP, 2023), which are all listed in Table 1.

Table 1 - Targets and Indicators of SDG 7

Targets	Indicators
7.1. Ensure universal access to affordable, reliable and modern energy services.	7.1.1. Share of population with access to electricity.

	7.1.2. Share of population with primary reliance on clean fuels and technology.
7.2. Substantially increase the share of renewable energy in the global energy mix.	7.2.1. Renewable energy share in the total final energy consumption (TFEC).
7.3. Double the global rate of improvement in energy efficiency.	7.3.1. Energy intensity – Measured in primary energy and GDP.
7.4. Enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.	7.4.1. International financial flows to support clean energy research and development and renewable energy production, including in hybrid systems.
7.5. Expand infrastructure and upgrade of technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing states, and land-locked developing countries, in accordance with their respective programmes of support.	7.5.1. Installed renewable energy-generating capacity in developing countries (watts per capita).

Source for Table 1: UN, 2023b

In 2020, it was estimated that 91% of the global population had access to electricity. This as 1.3 billion people gained access to electricity between 2010-2020. In terms of clean cooking fuels and technology access, this was estimated to be 69% on a global level in 2020. In general, electricity- and clean fuels access were found to be the lowest in African countries (UN, 2023c). The numbers on the renewable shares of the total final energy consumption (TFEC) imply a stagnated development on a global level. This as the share has remained around 17% since 1990 (World Bank, 2023a) and has increased by less than one percentage unit since 2015, making it 17.7% in 2019. The UN finds that the electricity sector is the greatest contributor to the growth of renewables, with 26.2% of its total consumption stemming from such sources. This while advancements are considered to have been limited in the other two energy sectors – those being transport and heating (UN, 2023c).

The global energy intensity, as in the amount of energy per GDP unit, has decreased on an annual average of 1.6% since 2015. This rate is approximately half of what it needs to be to achieve target 7.3. by 2030. In terms of target 7.4., the United Nations find that the financial flows to developing countries have continuously declined over the last year. Between the years of 2018 and 2019 alone, there was a decrease in investment flows of 23.6%. Finally, the renewable energy capacity per capita has increased by 57.6% since 2015, although the least developed countries have lagged behind in this development (UN, 2023c).

2.1.2. Critique of SDG 7

Given the formulation of SDG 7, emphasis is put on aspects such as affordability, reliability, sustainability and modernity (UNEP, 2023). In other words, by the year 2030, there should be universal access to energy that is clean, dependable and modern at an affordable price. This is an ambitious goal, which arguably require ambitious actions. As the targets and indicators of SDG 7 are supposed to guide countries to achieve of the goal, it is necessary that these are appropriate, effective and cover relevant aspects.

Fossil fuel energy sources and their emissions are considered to be one of the energy sector's major sustainability challenges (IEA, 2021; Ritchie et al., 2023a; UNDP, 2023a). Therefore, reductions in fossil fuel usage and emissions are essential parts to consider if one wish to achieve energy sustainability. However, none of the targets or indicators of SDG 7 explicitly considers fossil fuel usage or emissions (Madurai Elavarasan et al., 2022). These aspects are touched upon indirectly by target 7.2., which is related to renewable energy consumption. This as renewable energy sources could be seen as a replacement of fossil fuels, which also cause less emissions. However, even if there is an increase in the share of renewables, fossil fuel usage, and emissions can still increase in absolute terms. This is arguably a negative development in terms of energy sustainability, which is not directly considered by the official SDG 7.

Affordability and reliability are related to aspects of security. At the time of writing this paper, the world finds itself in an energy crisis, where higher prices are considered to fuel inflation, hinder economic growth and create poverty (IEA, 2023). Although target 7.1. of SDG 7 considers aspects of energy accessibility, there are no indicators that are more directly linked to security aspects of a country's energy system, such as energy prices or trade. The current targets and indicators of SDG 7 therefore fail to take three relevant aspects into account regarding today's energy system – fossil fuel usage, emissions and security (Madurai Elavarasan et al., 2022).

Further, Tucho and Kumsa (2020) argue that the energy related challenges are the result of deeply rooted socio-economic injustices, and that SDG 7 cannot be achieved without first breaking these. This while Munro et al. (2017) claim that SDG 7 is too focused on technological aspects, ignoring aspects of energy justice. For example, instead of having 'end state' goals such as universal access, it is argued that a broader goal like 'ending energy poverty' would be more efficient (Munro et al., 2017). Madurai Elavarasan et al. (2022) also write that there is a lack of data on several indicators of SDG 7, which makes it hard to monitor the progress of achieving the targets. More specifically, data generally only exist on indicators 7.1.1., 7.2.1. and 7.3.1. for most countries, and these indicators alone are argued to not deliver a proper picture of countries' energy sustainability (Madurai Elavarasan et al., 2022).

2.2. Ghana

2.2.1. A Brief Description

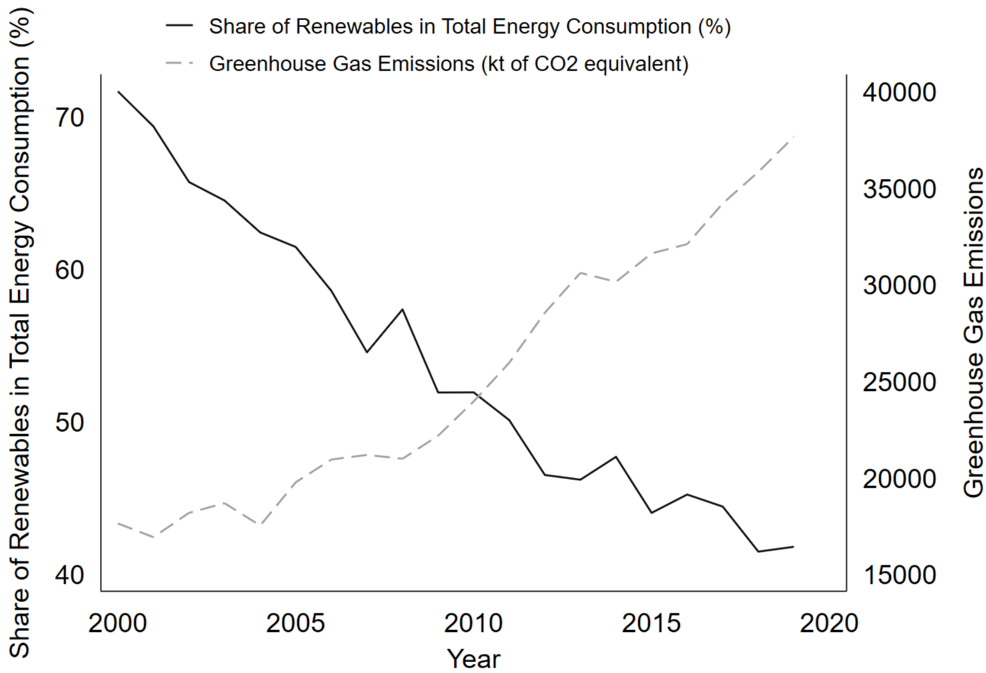
The origins of the modern country of Ghana stems from the former British colony the Gold Coast (Gocking, 2005). As the colonial name implies, Ghana is a coastal country that faces the Atlantic Ocean to the south (World Bank, 2023b). It is located in Western Africa (Gocking, 2005) and shares borders with Togo, Cote d'Ivoire and Burkina Faso (World Bank, 2023b). Ghana consists of 238,540 square kilometers of land (Gocking, 2005) and was the home of approximately 33 million people in 2021 (World Bank 2023c).

Ghana became an independent country on the 6th of March 1957, and adopted a democratic constitution in 1992 (Gocking, 2005). It is one of the highest-ranking countries in Africa regarding freedom of speech and press (World Bank, 2023b), and is one of the seven Sub-Saharan (SSA) countries labelled 'Free' by Freedom House (Freedom House, 2020). Further, the country has experienced significant economic growth and development during the 21 century, with an average annual GDP per capita growth of 3% (World Bank, 2021). The IMF entitles some of this development to the democratization of the country, as the economy since then has become more formal and gained an effective taxation system (Edmond, 2019).

Further, Ghana is a country with several natural resources, which has also fuelled the development of the country. Although the country is one of the world's largest exporters of both gold and cocoa products, the natural resource that is considered to have propelled the Ghanaian economy the most as of recently is oil (Edmond, 2019). In 2007, oil reservoirs were discovered 60 kilometres outside of Ghana's coast, which started being commercially extracted in 2010 (Graham et al., 2016).

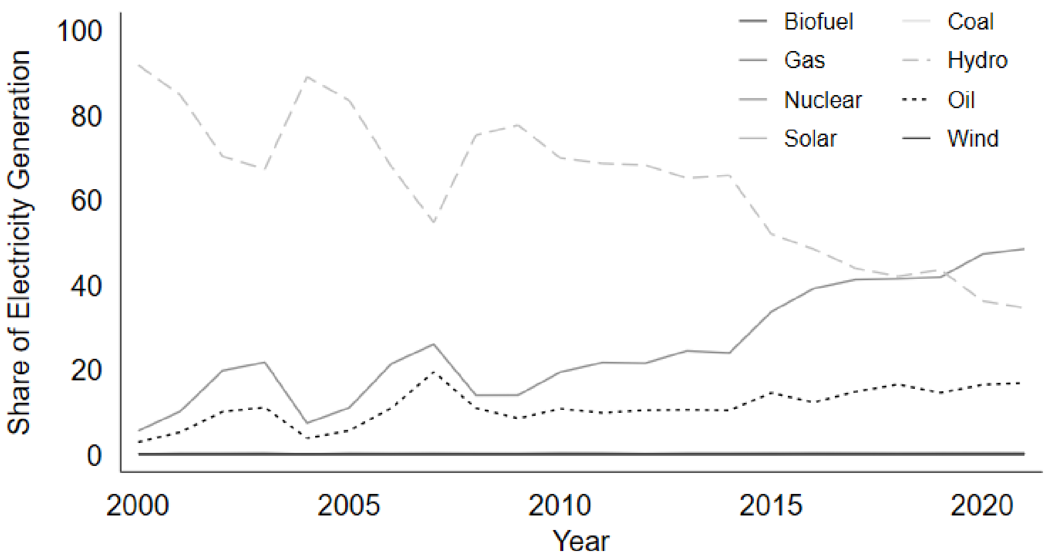
2.2.2. Energy, Electricity & Sustainability

There are sustainability challenges to Ghana’s development path. For one, there has been a significant increase in GHG-emissions. At the same time, the consumption of renewable energy has strongly declined (World Bank, 2023c). The development of these indicators is displayed in Graph 1, with renewable consumption on the left-most y-axis, and emissions on the right y-axis. As increased emissions and lower renewable energy usage are seen as drivers of climate change, this is arguably an unfortunate development. However, energy sustainability is arguably not only an environmental concern, but also a social and economic one. It should therefore be noted that the below graph might not tell the entire story and cannot be used to sufficiently answer the research question of this thesis.

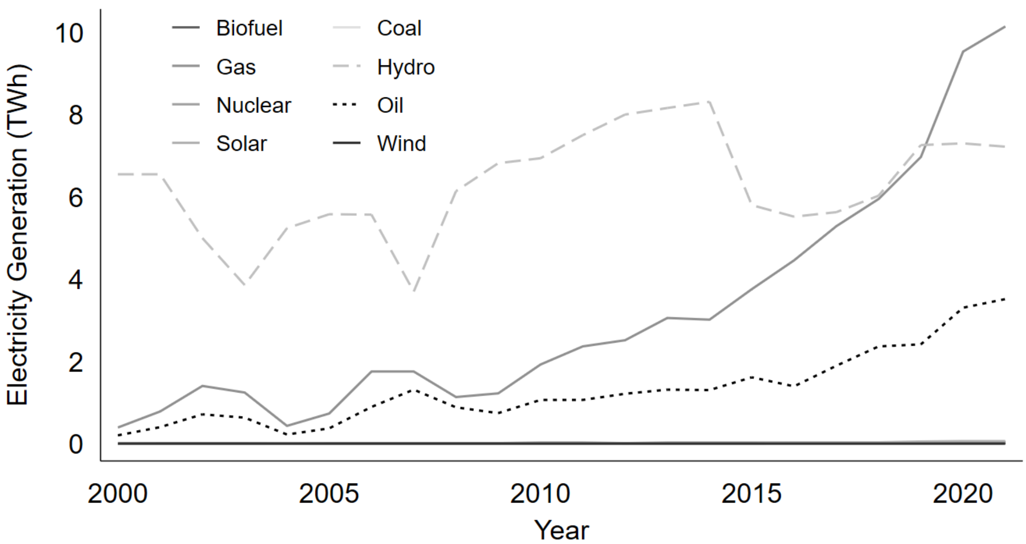


Graph 1: Ghana’s Renewable Energy Consumption & Greenhouse Gas-emissions (World Bank, 2023c).

Around 70% of Ghana’s land area is located in the Volta River basin (Ahmed & Gong, 2017), which is one of the largest river systems in Africa (GWP, 2021). The Akosombo dam is the country’s first, and today largest, hydroelectric powerplant and its construction was finished in 1965 (Miescher, 2021). A large share of Ghana’s electricity has historically been generated from hydropower, but this has continuously decreased during this century. Instead, gas and oil have gained an increased importance in Ghana's electricity provision. In 2019, gas overtook hydropower as the main electricity generating source. Further, Ghana generates no electricity from coal, nuclear or wind power. Electricity generation from solar power did not start extensively before 2017, and does as of date still provide a significantly small share of Ghana’s electricity (Ritchie et al., 2022a). All of this is seen in Graph 2 and 3 below.



Graph 2: Shares of Ghana's Electricity Generation (Ritchie et al., 2022a).



Graph 3: Electricity Generation in Ghana in TWh (Ritchie et al., 2022a).

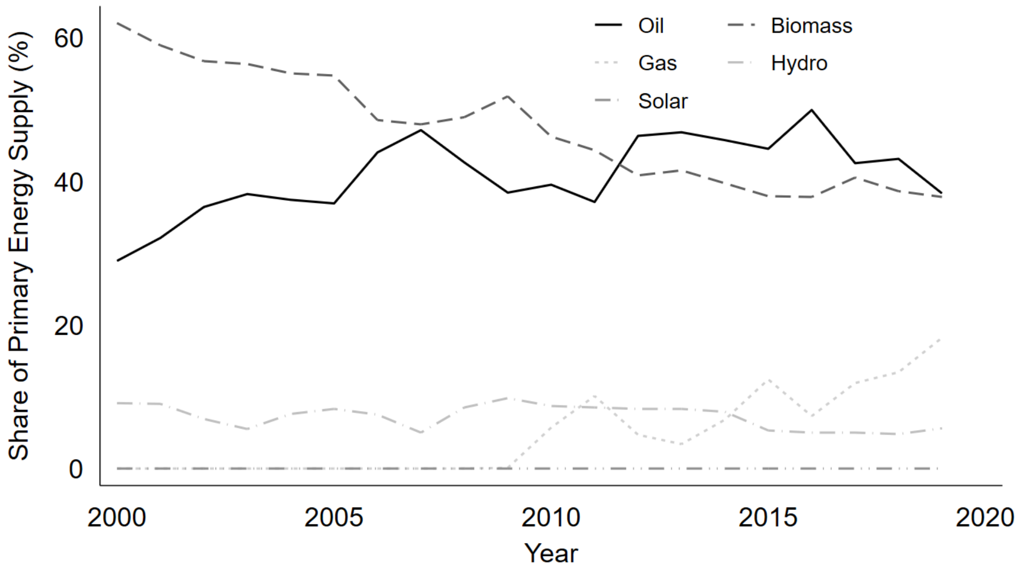
The above patterns in electricity generation could be explained by two major factors. One is that Ghana, as mentioned previously, found oil- and gas resources in 2007 (Graham et al., 2016). According to the Energy Information Administration of the United States (EIA), Ghana tends to export its oil, while gas is more often used domestically in the power sector (EIA, 2018). This would explain why gas has a higher share in Ghana's electricity mix than oil. Further, gas started being extracted from the major fields between 2014 and 2018 (Fulwood, 2021), which could potentially explain the sharper increase of gas in the electricity mix from 2014 onwards.

The other factor is related to energy security. Throughout its modern history, Ghana has experienced multiple power-related crises (Adusah-Poku et al., 2022; Kumi, 2020). This has resulted in what is commonly referred to as ‘Dumsor’, i.e. repeated and irregular electricity outages. Dumsor is translated to ‘on-off’ in Akan and are estimated to have caused both unemployment and reductions in GDP growth (Kumi, 2020). The Dumsor phenomenon is considered to be due to higher demands than there are supplies of electricity (Adusah-Poku et al., 2022; Kumi, 2020).

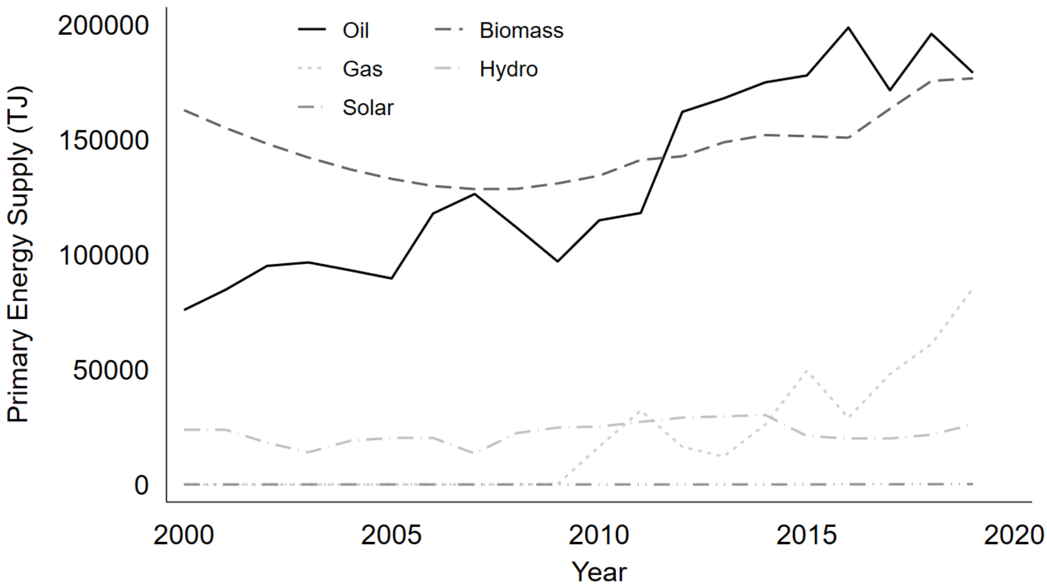
The prevalence of Dumsor is partly explained by Ghana’s high dependence on hydropower. Ghana’s energy system has therefore been dependent on climate and weather conditions, e.g. droughts and rainfall (Kumi, 2020). Population growth and aging infrastructure is considered to stress the hydropower capacity in Ghana (Acheampong et al., 2019). Further, Ghana’s gas consumption was previously dependent on imports from Nigeria, which has been described as irregular (Kumi, 2020) and erratic (Adusah-Poku et al., 2022). To escape the state of Dumsor, Ghana has expanded its generation capacity on other sources, and reduced its dependence on hydropower (Kumi, 2020).

Up until now, it seems like Ghana has moved away from renewables to fossil fuels, at least in terms of electricity generation. The term electricity is at times used interchangeably with the term energy, although electricity in theoretical meaning only makes up one part of human energy usage. The other two parts are transports and heating (Ritchie et al., 2022b). Therefore, if one is interested in energy sustainability, one should also consider energy data, and not only data on one of energy’s three parts.

However, a similar pattern to what is seen in the electricity data is also seen in Ghana’s energy data. Ghana’s total primary energy supply (TPES) (i.e. total energy used) by source, both in absolute and relative terms, are shown in Graph 4 and 5 below.



Graph 4: Shares in Ghana's Total Primary Energy Supply (ECG, 2020).



Graph 5: Ghana's Total Primary Energy Supply in Terra-Joule (ECG, 2020).

When consulting electricity data, hydropower and gas are the dominating sources, while biomass and oil serve as the main sources in the energy data. A potential explanation to this is that the usage of petroleum - a oil-related product - in Ghana's transportation sector has more than doubled since year 2000 (ECG, 2020). This while traditional biomass usage often does not include electricity generation (Goldemberg & Coelho, 2004), but is more commonly used in developing countries to cook food, heat homes and generate light (Bildirici & Ersin, 2015; Ramsay, 1985).

Graph 4 and 5 show that while hydro- and solar power constantly have a small share in Ghana's TPES, gas is increasing in importance over the examined period. This while there has been an increase in the share made up of oil, and a decrease in the share made up by biomass. This last observation could be due to the economic development of Ghana, which contributes to phasing out biomass in favour for more modern sources of energy. The increased dependencies on fossil fuels can also be seen as oil make up a larger share than hydropower in Ghana’s TPES soon after 2010, while the usage of gas becomes larger than the usage of hydropower in 2014.

3. Literature Review

This section presents a brief literature review related to the relationship between economic development and energy, as well as energy usage in Africa.

3.1. Energy & Development

Energy usage has enabled many things for humanity. Examples of such are production, travels, and higher quality of life (Bilgen, 2014; Smil, 2004). Therefore, energy plays a vital role in human society as it is an essential input in most sectors of our economies and everyday activities such as cooking and heating (Bilgen, 2014; Rosen, 2009; Smith et al., 2013).

Prior to the Industrial Revolution (IR), energy came mostly from food and firewood (Kander et al., 2013; Smil, 2004). This energy mix made up what Kander et al. (2013) call the 'organic economy'. In this economy, human society had limited access to energy, which further hindered growth in the European economies. However, when energy started to be extracted from coal, the constraint of the organic economy was broken, the industrial economy was born and fossil fuels started to dominate the global energy mix (Kander et al., 2013).

Energy usage has increased over twenty times globally since the IR. This is a much faster growth than the human population has experienced during the same time, which imply that population growth is not the only thing that cause the higher energy usage. Instead, this indicates that there are other things that have led to this increase. Examples of such things are changes in energy consumption patterns, or growth of energy-intensive economic sectors (Grübler, 2004).

Given what is mentioned above, it would seem like the relationship between energy and development is relatively simple. That is, no energy means no growth, while more energy means more growth. However, the literature imply that this relationship is a little more complicated than that. When energy is scarce, energy is indeed viewed as a major constraint to growth (Stern, 2011), just as in Europe before the IR (Kander et al., 2013). But as energy becomes more available, energy shifts from a constraint to an enabler of growth. This as energy makes it possible to produce at a larger scale, but also to increase the efficiency in the production through technology (Stern, 2011).

However, developed countries eventually starts using energy more efficiently, meaning that the economy becomes less energy intensive. In other words, the same amount of production becomes possible at smaller amounts of energy. The reason for this is believed to be that high income countries use higher quality energy sources and experience technological innovations to a higher extent. (Stern, 2011). According to Stern (2011), economic production should therefore be seen as the output of labour, capital and energy.

Grübler, (2012) write that there is a great need for transitioning the global energy system towards sustainability. This is partly because the sector is a major contributor to climate change, but also that millions of people are without proper energy access (Grübler, 2012). There are multiple suggestions how such a sustainability transition could occur, including increased energy intensities (Sugiyama et al., 2013), phasing out of fossil fuels (Shindell & Smith, 2019) and carbon binding technologies (Wennersten et al., 2015).

3.2. Energy in Africa

The African continent is considered to be abundant in renewable energy sources and possess great oil and gas resources. However, approximately two-thirds of the population in SSA:n countries do not have access to electricity (Hafner et al., 2018). Hafner et al. (2018, p.1) describes energy access as "… one of Africa's greatest obstacles to social and economic development". By the year 2100, it is estimated that Africa will house 40% of the global population. This is an increase from 16% of the global population, as of 2018. Due to this population growth and potential future development trajectories, energy demand is expected to significantly increase on the African continent (Hafner et al., 2018).

Traditional biomass (e.g. firewood, charcoal) is the dominating source of energy of countries in SSA (Hafner et al., 2018). However, Owen et al., (2013) find that most energy policies in Africa focus seem to phase out biomass usage. According to the authors, this is not necessarily for the better. For one, the authors argue that these policies are not in line with either reality or future projections. This as the number of people relying on biomass have significantly increased in several SSA:n countries, and is believed to continue doing so if populations grow and poverty persists (Owen et al., 2013).

However, there is no strong consensus regarding the sustainability status of biomass in the literature. On one hand it can be considered a renewable energy format, as forests and trees are reproducible. Biomass is by some also considered to be a secure and highly available source of energy, with job-creating opportunities (Owen et al., 2013). On the other hand, too extensively usage can disrupt natural habitats and biodiversity. Further, burning of wood can have severe impact on people's health, due to the creation of smoke it causes (Tucho & Kumsa, 2020).

The second most common energy source in African TPES is oil, followed by hydropower and gas. Africa stands for 10% respectively 8% of all globally traded oil and gas (Hafner et al., 2018). However, these energy sources are not evenly spread out across the continent. A bit more than 75% of all African oil is produced in four countries – Nigeria, Algeria, Libya and Angola (Oduyemi et al., 2021). Two of these countries (Algeria and Nigeria) are also the continent's top two largest gas producers (Esily et al., 2023). However, it is estimated that there has been an 240% increase in discovered oil and gas reserves in Africa between 1980-2013. During this century there have been many new reserve discoveries, and not only in established producer countries. Example of countries that now produce oil and gas after recent discoveries are Chad, Ghana and Mozambique (Graham & Ovadia, 2019).

Renewable energy extraction is currently not extensively developed in African energy systems. When excluding biomass from the energy mix, modern renewable energy sources make up only 8% (Hafner et al., 2018). In their work, Kabir Aliyu et al. (2018) lists several aspects that serves as obstacles for the development of renewable energy in Africa. Among these are lack of interest from governments and investors, insufficient policies and funding as well as lack of awareness and knowledge (Kabir Aliyo et al., 2018).

4. *Empirical Strategy*

This section will go through everything related to the empirical strategy in terms of designing the SDG 7 composite index for Ghana. This involves everything from which indicators and parameters that are considered and why, to how these then are generated, normalized, assigned weights, and aggregated. However, this section starts with a brief description of what composite indices are and how these are thought to measure development.

Much inspiration and guidance for generating the index of this thesis is found in Madurai Elavarasan et al.'s (2022) paper. However, it is important to note that these indices are not the same, and that their differences are described throughout the thesis.

4.1. Composite Indices

Composite indices gained widespread attention and interest after the Human Development Index (HDI) was introduced in 1990 (Santos & Santos, 2014). Even if there is no official definition of what a composite index is (Greco et al., 2019), they are generally described as a composition of indicators that aim to measure complex concepts. In turn, complex concepts can be understood as outputs that are the result of multiple aspects (Boyseen, 2002; Greco et al., 2019; OECD, 2008), such as development (Boyseen, 2002).

However, composite indices are not simple measures. The construction of composite indices includes multiple steps, which can all affect the output of the index (Booysen, 2002; Greco et al., 2019). Therefore, index construction depends more on its creator rather than any specific rules (OECD, 2008). Therefore, there is always a risk that composite indices present a somewhat skewed picture of reality (Booysen, 2002). If policy design relies on a biased or poorly constructed composite index, this could potentially have major consequences (OECD, 2008).

The usefulness and practical value of composite indices have been discussed in the literature. Boyseen (2002) write about research that claims that indices like the HDI generate no clear advice on policies, and that such indices have not contributed to better development policies. Another part of the discussion is concerned about what story composite indices tell that individual indicators cannot (Boyseen, 2002).

The purpose of composite indices is to present a summed-up picture of something complex, e.g. development performance (Greco et al., 2019; OECD, 2008). This aspect is believed to be the major asset of composite indices - complex development patterns are believed to be become more attainable and simpler to understand, even for the wider public and media. This as interpreting multiple development indicators separately can still be considered more difficult (Booysen, 2002; Greco et al., 2019; OECD, 2008). Composite indices therefore argued to make it easier to monitor progress and trends in development performance, which is potentially why they are growing in numbers every year (OECD, 2008).

4.2. Indicators & Parameters

Figure 1 presents the indicators, parameters and measures of this thesis's SDG 7 composite index. Each indicator includes between 1-3 parameters, which are all expressed in different values. Through normalization, each indicator is generated into a value between 0-1. The reason for this range is simply to obtain a measure that can more easily be interpreted and understood. In this sense, the closer an energy systems scores to the value of 1, the more sustainable it can be considered to be. Similarly, energy systems can be described as less sustainable the closer it gets ranked to 0 on the SDG 7 composite index.

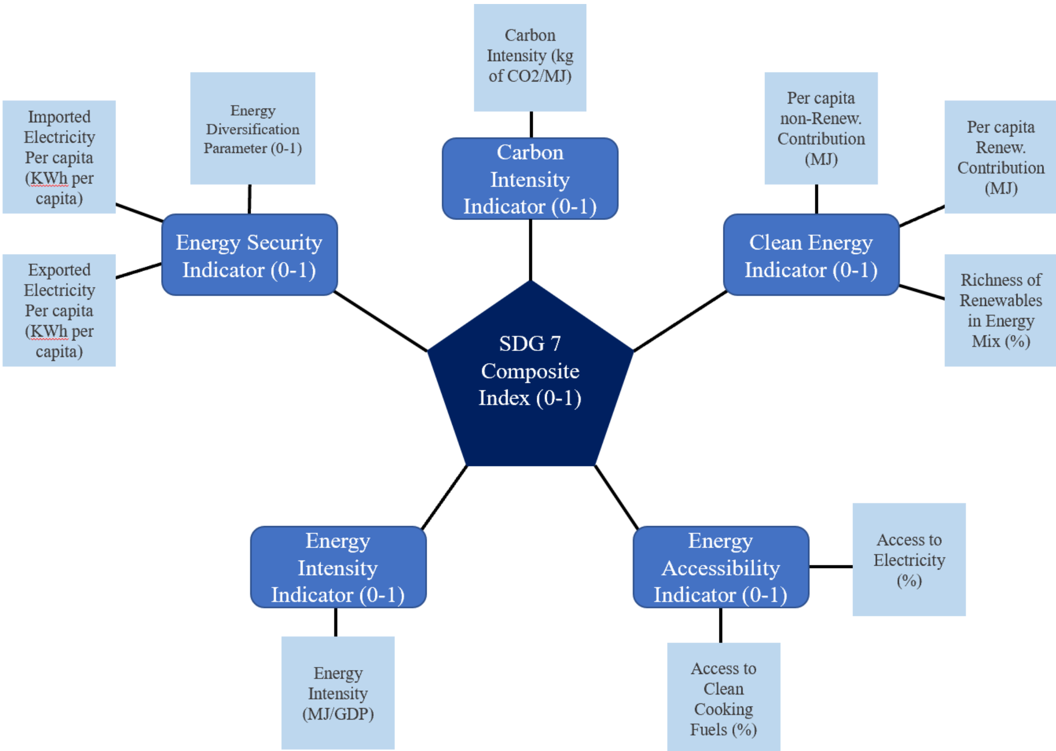


Figure 1: The indicators and parameters of the SDG 7 Composite Index

4.2.1. <u>Selection</u>

The purpose of the SDG 7 composite index is to cover as many aspects as possible that are relevant for evaluating the sustainability of a country's energy system. This resulted in a composite index containing 5 indicators and 10 parameters in total, to a large extent inspired by the ones included in Madurai Elavarasan et al.'s (2022) paper.

As previously mentioned, a big challenge related to the global energy system is fossil fuel usage (IEA, 2021; Ritchie et al., 2023a; UNDP, 2023a) With targets and/or indicators directly related to emission reductions, SDG 7 could guide countries to become more sustainable. However, SDG 7 does not offer such guidance, which is one of Madurai Elavarasan et al. (2022)'s major critiques of the goal.

In order to take emissions into consideration when evaluating the sustainability of Ghana's energy system, the composite index of this thesis includes the *Carbon Intensity* indicator. This indicator includes one single parameter with the same name. Carbon intensity is measured as kilograms (kg) of CO_2 emissions per unit of energy (Mega joules; MJ), where lower values indicate lower emissions per unit of energy. This means that an energy system is considered more sustainable when carbon intensity is low.

A popular solution to the energy-sustainability challenges is to increase energy production from cleaner, renewable sources (IEA, 2022; UN, 2023a). When examining energy sustainability, it is therefore arguably relevant to consider the amount of both renewable and non-renewable energy production. The *Clean Energy* indicator is therefore included in the composite index to cover these aspects. Three parameters are considered in this indicator, these being renewable richness in the energy mix, per capita non-renewable contribution and per capita renewable contribution.

Renewable richness in TFEC - the total final energy consumption – is an official target and indicator of SDG 7 (UN, 2023b). However, when examining renewable richness in the composite index, TPES – the total primary energy supply – will be considered. The reason for this is that Madurai Elavarasan et al. (2022) argue that TPES better represent the total available energy of a country. This as TPES include both consumed energy, but also energy lost due to transmission, while TFEC only considers the consumed part (Madurai Elavarasan et al., 2022). According to me, the argumentation of Madurai Elavarasan et al. (2022) holds, which is why renewable richness in TPES is included in the *Clean Energy* indicator of this thesis. The interpretation of this parameter is that the larger the share of TPES that comes from renewable sources, the more sustainable the energy system.

The per capita contribution parameters that are included in this thesis's composite index are considered to further diversify the prevalence of clean energy in the country. This as renewable richness alone might not present an entirely accurate picture. For example, consider two countries - Country 1 has a higher level of total TPES, while Country 2 which has a lower level of total TPES. However, Country 1 has a lower richness of renewables in their TPES than Country 2 do. In this scenario, it could be the case that Country 1 in absolute terms obtain more energy from renewable sources than Country 2. This depending on the size of Country 1's TPES. However, this is not something that the richness-parameter can take into account (Madurai Elavarasan et al., 2022).

Potentially, larger renewable energy extraction in absolute terms could indicate that an energy system has come a longer way in its sustainability transition. This as larger amounts of renewable energy indicate that there are extensively more developed infrastructure and future potential for renewable energy, which is arguably important for a sustainability transition. Therefore, not considering the contribution of renewable respectively non-renewable sources might not fully describe the sustainability state of the energy system, which could further result in a skewed *Clean Energy* indicator.

The contribution parameters are generated from the TPES, and TPES tends to be larger the larger the population of a country is (Madurai Elavarasan et al., 2022). To account for this, the contribution parameters are presented as per capita values, just as done in Madurai Elavarasan et al.'s (2022) work. The interpretation of the renewable contribution per capita parameter is that the larger the contribution, the more sustainable the energy system. The reverse holds for the non-renewable contribution per capita. The renewable- and non-renewable contribution per capita therefore has a positive respectively a negative relationship with the *Clean Energy* indicator.

As previously mentioned, energy constraints can limit economic development and well-being (Ritchie et al., 2023b; Stern; 2011). Further, unclean cooking fuels is a human health threat (WHO, 2022). Given this, *Energy Accessibility* is an indicator of the SDG 7 composite index which will measure social aspects of Ghana's energy system. This indicator is important to include as energy accessibility is a foundational part of SDG 7 (UN, 2023b). The *Energy Accessibility* indicator include the same parameters as the official goal (UN, 2023b), i.e. access to electricity and access to clean fuels and technologies for cooking. These parameters are presented as percentage shares of the population.

Energy efficiency is considered by SDG 7 in target 7.3. (UN, 2023b). This aspect of a country's energy system is therefore also included in the composite index under the *Energy Intensity* indicator. The indicator only includes one parameter, which is measured as unit of energy (MJ) per $1 of GDP.

In the literature, energy intensity has been found to initially increase when a country develops. This due to increasing usage of energy. However, a trend is seen in developed countries of increasing energy efficiencies (Stern, 2011). This means that a country can produce more for each unit of energy than before, which is positive in terms of sustainability. In other words, lower intensities and higher efficiency in terms of energy is considered as more sustainable than higher intensities and lower efficiency. Therefore, the *Energy Intensity* indicator is negatively correlated to the country's overall sustainability performance.

Last but not least is the *Energy Security* indicator. As part of the formulation of SDG 7, it is stated that energy should be affordable and reliable (UN, 2023b). This is in turn related to how secure access to energy is (Madurai Elavarasan et al., 2022). This indicator is therefore considered to display important aspects related to social sustainability of a country's energy system. To account for energy security, trade in electricity and the diversification of the energy mix is considered.

In this setting, a more diverse energy mix would be considered less risky and more sustainable. This as the prevalence of the energy system is not dependent on any one source and is not heavily affected by losses in any source. In the *Energy Security* indicator, diversification is measured through a special parameter designed by Madurai Elavarasan et al. (2022), which is called the 'Energy Diversification Parameter' (EDP). The EDP ranges between 0-1, where 1 is considered to imply that an energy system is very diversified. This while a score closer to 0 is to be interpreted as lower levels of diversity. The construction of this measure is described in the upcoming subsection.

For trade, per capita imports and exports of electricity is considered. These are measured in traded kilowatt hours (KWh) per capita, and are considered to display how much electricity that needs to be traded in order to meet the domestic demand. In the setting of this index, higher import levels are considered to imply lower energy security, while larger volumes of exports imply higher energy security. This as exports can be considered to indicate that a country has a surplus of electricity, as they can use their generated electricity in trade, which further imply that the country is capable of fulfilling their electricity demand more independently. This while electricity imports imply that there is a deficit, and imports are needed to fulfil the demand. Due to this, electricity imports are considered to negatively correlate with energy security, while electricity exports is considered to positively correlate with energy security.

The *Energy Security* indicator of Madurai Elavarasan et al.'s (2022) composite index uses parameters related to trade in energy. This instead of trade in electricity, which I used in the composite index of this thesis. The reason for this is further explained in Section 5.3. However, it should be noted that the reasoning presented above about the implications that electricity imports respectively exports on energy security is very similar to the interpretation of Madurai Elavarasan et al. (2022) of energy imports and exports on security.

To sum up – all indicators in the composite index of this thesis are included as these represent different sustainability aspects that are all considered essential for energy sustainability. The *Energy Accessibility*, *Energy Intensity* and part of the *Clean Energy* indicators are official indicators of SDG 7. This while the *Carbon Intensity* and *Energy Security* parameters is not. These last two indicators are considered to cover important aspects of a sustainable energy system, which is why these are added to the composite index of this thesis.

4.2.2. Parameter Construction

To produce the indicators and parameters needed for the composite index, the collected data have been manipulated in different ways and to different degrees. In the purpose of parameter construction, the data that have not been manipulated in any way are energy intensity, access to electricity and access to clean fuels and technologies for cooking. This as these parameters were already in the desired format. In Appendix 1, a simplified description of how each parameter was generated can be found in Table A1.

One essential modification of the data to note is the transformation of units. The data on Ghana's TPES (ECG, 2020) is expressed in kilotons of oil equivalent (ktoe), while Madurai Elavarasan et al.'s (2022) presents this data in terajoules (TJ) and megajoules (MJ). To obtain the data in the right measure units, several steps were taken. First, after consulting a unit converter website (Unit Juggler, 2023a) and counter-checking its values (NE, 2023), the ktoe values are multiplied with 41,868. This to obtain the values in gigajoules (GJ). The reason for first converting the values to GJ was simply to make steps along the calculations, to avoid making mistakes. Second, the GJ values were divided by 1,000, to get TJ-values (Check Your Math, 2023a; NE, 2023).

After this initial unit transformation, I manually created some of the parameters. One was renewable richness in the TPES. This parameter is the result of dividing the amount of energy provided from renewable sources with the total amount of energy provided by all sources. Renewable resources are here considered to be biomass, hydropower and solar. Further, Renewable/Non-renewable contribution per capita are constructed as the amount of energy provided by renewable respectively non-renewable sources per person in the Ghanian population. Again, biomass, hydro and solar are renewable resources, while oil and gas are considered to be non-renewable sources.

As the contribution variables are presented in Madurai Elavarasan et al.'s (2022) paper in MJ, I had to transform the TPES-data again, as these at this stage was presented in TJ. The MJ-values were obtained by multiplying the total amount of energy provided from renewable and non-renewable sources with one million (Check your math, 2023b; NE, 2023). Finally, the data was divided with the total population of Ghana of the same year, to gain the parameters in per capita format.

Carbon intensity is measured as kg of CO2 emissions per MJ in Madurai Elavarasan et al.'s (2022) work. As the collected CO2 emissions-data is in kilotons (World Bank, 2023c), these values had to be multiplied by a million become the right unit (Ekonomifakta, 2007; Unit Juggler, 2023b). The carbon intensity parameter was finally constructed through dividing CO2 emissions in kilos with the TPES measure in MJ.

For generating the import and export per capita variables, the data was first transformed from Giga-watt hours (GWh) to KWh. This was done by multiplying the GWh values with a million (Convert Measurement Units, 2023; NE, 2023). This unit-transformation was done purely to obtain values that where easier to interpret. To finalize, the transformed KWh data was divided by the population of Ghana the corresponding year.

The last parameter to be constructed is the EDP – the Energy Diversity Parameter. This parameter is used to explore how diversified the energy provision of a country is, as a measure of resilience in the energy system. This parameter is designed by Madurai Elavarasan et al. (2022), and their formula is used for calculating it for this thesis as well.

In the EDP, Madurai Elavarasan et al.' (2022) consider nine energy sources which they divide into four tiers. Each energy source is given a score based on aspects of availability, reliability, intermittency and supply chain risks. The energy sources and their scores are listed in Table 2, which is a replication of Table 5 from Madurai Elavarasan et al.'s (2022, p.9) paper.

Table 2: Replication of Madurai Elavarasan et al.'s (2022, p.9) Table 5

Energy resource security ranking score for various energy resources

Tiers	Energy Source	Availability	Reliability	Intermittency	Supply chain risks	Security score
1	Nuclear, Geothermal	Nuclear - High Geothermal - Very high	High	Low	Low	4
2	Hydro, Wind, Solar	Hydro - Geographically limited Wind - High Solar - High	High	High	Low	3
3	Bioenergy, Oil	Bioenergy - High Oil - Limited	Moderate	Low	Moderate	2
4	Coal, Gas	Scarce	Low	Low	High	1

The logic is as follows; the higher the score, the more secure and less risky a resource is considered to be. Given this, nuclear and geothermal energy are argued by Madurai Elavarasan et al. (2022) to be the most reliable sources in the long term. This is motivated with that there are no GHG emissions from nuclear, while geothermal is considered to be more reliable than other renewable sources. Hydropower, wind and solar, which are assigned the second highest security score, are on the other hand described as sources more conditioned on weather and climate. This is argued to increase the risks of intermittencies, which is why they are assigned a lower security score (Madurai Elavarasan et al., 2022).

One step lower on the security score ladder is bioenergy (i.e. biomass) and oil. This ranking is explained with that there is a limitation on how much these sources that can be extracted in a way that is sustainable. Further, compared to other fossil fuels, oil is described to be easier to extract, store and manage. This is why oil gets the second lowest point, while coal and gas get the lowest. Coal and gas are instead described as scarce resources that are more difficult to manage, generate more emissions and require more energy to be exploited (Madurai Elavarasan et al., 2022).

In the case of Ghana, one could potentially argue that gas is not a scarce resource, although it could eventually become one if it is extracted too extensively. Further is the debate regarding the sustainability and risk levels of nuclear energy (Lawson, 2023). However, Ghana extract no energy from nuclear (or thermal) sources. The question then becomes what should be considered more or less risky, to establish new nuclear plants or continue to develop other the extraction from other sources. This is not something that this thesis will take a stance on, and I chose to keep the rankings of Madurai Elavarasan et al. (2022). This as I want to be able to produce an EDP that is similar to the one produced by Madurai Elavarasan et al. (2022).

The EDP parameter is calculated using the following equation (Madurai Elavarasan et al., 2022):

$$EDP = \frac{k \times \sum_{i-1}^{k}(TS_i) \times Energy\ resource\ contribution\ (\%)}{n \times (TS)_{max}} \quad (1)$$

In this equation, *k* is the number of energy resources that are used in the considered country. (TS_i) represents the score of the energy resource presented from Table 2. The numerator of Equation (1) is therefore the sum of the scores multiplied with the share the energy source makes in the TPES, which is then multiplied by *k*, i.e. the number of resources included in the TPES. This while *n* is the total number of sources considered in Table 2. $(TS)_{max}$ is the highest score assigned from Table 2, meaning that *n* is equal to 9 while $(TS)_{max}$ equals to 4. The denominator of Equation (1) is therefore equal to 36 (Madurai Elavarasan et al., 2022).

The result of Equation (1) is a parameter that ranges between the values of 0 to 1. A higher EDP indicates a higher degree of diversification in the energy mix, and therefore also higher levels of security (Madurai Elavarasan et al., 2022).

4.3. Normalization

To be able to compare the different indicators and aggregate them to one composite index, the variables need to be in the same values (OECD, 2008). It is therefore necessary to normalize the data before generating the SDG 7 composite index. As in Madurai Elavarasan et al. (2022) paper, the normalization method of choice in this thesis is a min-max method. This means that the normalization is performed using the maximum respectively the minimum values of each indicator (OECD, 2008).

A critique to min-max methods is that the output is dependent on what the maximum and minimum values actually are (OECD, 2008). This means that potential extreme values can impact the result of the normalization. However, the choice of normalization method was based on two aspects. First, in the purpose of producing a SDG 7 composite index that is similar to Madurai Elavarasan et al.'s (2022), a similar normalization method was considered important. Second, the min-max method produces normalized values in a range between 0 to 1, where 1 represents the highest value (OECD, 2008). The advantage of this normalization method is that it will result in a SDG 7 composite index within the same range (i.e. 0-1), which arguably makes index values more easily to interpret.

Through the normalization process, I controlled for extreme values – i.e. outliers - in the data, using the same method as Madurai Elavarasan et al. (2022). Through this check-up, outlier values were detected in four of the six normalized parameters. However, by replacing the 'outliers' with the next maximum- or minimum value that is not an outlier, it was found that the impact of the outliers on the normalized values were small. If the outlier values were to be handled properly, this would result in removing the outlying data, i.e. removing the years with outlier values. This was not considered a desirable solution, as the ambition of this thesis is to examine Ghana's energy sustainability performance over as much time as possible. Due to all this, no action was taken against the outlying values. A fuller description of the outlier values, how these were detected and their impact on the data is found in Appendix 2.

Only the variables not expressed in in shares of percentages needed to be normalized. The normalized parameters are therefore non-renewable contribution per capita, renewable contribution per capita, imports per capita, exports per capita, energy intensity and carbon intensity. The normalization method used by Madurai Elavarasan et al. (2022) looks like the following:

$$I_i = \frac{x_i - min_i}{max_i - min_i} \tag{2}$$

$$I_i = \frac{max_i - x_i}{max_i - min_i} \tag{3}$$

In the above equations is I_i the normalized parameter value of indicator i and x_i is the original value of indicator i. This while max_i and min_i is the maximum respectively minimum value of indicator i, across all considered countries. Which equation that is used to normalize the parameters depends on their overall relationship with the concerning indicator or overall index. For example, renewable contribution per capita is considered to positively impact the clean energy indicator. This while non-renewable contribution per capita is seen to influence the clean energy indicator negatively. Therefore, Equation (2) is used to normalize the renewable contribution parameter, while equation (3) normalizes the non-renewable contribution parameter (Madurai Elavarasan et al., 2022).

To remind the reader, Madurai Elavarasan et al. (2022) generate their composite index using 40 countries for the year 2018 alone. This means that the normalized values range between the different country values. For example, energy intensity-values are normalised in Madurai Elavarasan et al.'s (2022) paper using the highest value (Iceland; 13) and lowest value (Ireland, Malta; 1.4) amongst the considered countries.

As this thesis considers only one country, the normalization will occur using Ghana's maximum and minimum values of each parameter. This means that the normalization occurs by comparing Ghana's sustainability performance at different points in time with Ghana's sustainability performance over time. This arguably bias this composite index towards the performance of Ghana. It is therefore important to notify the reader that the resulting SDG 7 composite index of this thesis should not be interpreted by its absolute values. This further means that the outcome for the year 2018 on the index of this thesis cannot directly be compared with the index outcome from Madurai Elavarasan et al. (2022). A justified comparison between the two indices would not be possible without merging the dataset of this thesis with the dataset of Madurai Elavarasan et al. (2022), and then normalizing the data within the same range.

However, the index output of this thesis will be useful to explore trends in Ghana's energy sustainability performance. The index will evaluate Ghana's sustainability performance over time, which will contribute to an understand whether the country's energy system is becoming more or less sustainable over the considered period, both overall and in specific fields. Further, this could produce valuable insights in terms policy design, and led Ghana to more sustainable practices in terms of energy. Therefore, the work of this thesis will use a min-max normalization method but take caution for the impact this normalization method has on the index outcomes.

For parameters with a positive correlation with designated indicator or entire index, using the following formula;

$$I_{it} = \frac{x_{it} - min_{t \in T} \min(x_{it})}{max_{t \in T} \max(x_{it}) - min_{t \in T} \min(x_{it})} \quad (4)$$

This while the parameters with a negative correlation are normalized with this equation:

$$I_{it} = \frac{max_{t \in T} \max(x_{it}) - x_{it}}{max_{t \in T} \max(x_{it}) - min_{t \in T} \min(x_{it})} \quad (5)$$

I_{it} is here the normalized value of indicator *i* at time *t*, while x_{it} is the original value of indicator *i* at time *t*. $max_{t \in T} \max(x_{it})$ is used to express the maximum value of indicator *i* over the entire period, while $min_{t \in T} \min(x_{it})$ represents the minimum value over the entire period. A notation to these formulations is that the normalization must be redone every time new data is added, for example in the event for adding a new year. This is only relevant in the case of someone wanting to expand the resulting index of this thesis. This as an added point in time (t) might affect which values that are maximum and or minimum values, which in turn would affect the normalization (OECD, 2008).

Given the described relationships between each parameter and the indicator or overall index from section 4.2.1., Equation (4) was used to normalize the parameters per capita electricity exports as well as per capita renewable energy consumption. This while Equation (5) was used to normalize per capita electricity imports, per capita non-renewable contribution, carbon intensity and energy intensity. The original parameter values are presented in Table A3, while the normalized values are presented in Table A4. Both tables are found in Appendix 3.

4.4. Weightage & Aggregation

When constructing indicators and indices, the assigned weights to each parameter can affect the final output. Therefore, weights must be assigned with care and motivation. Just as Madurai Elavarasan et al. (2022), I choose an Analytic Hierarchy Process (AHP) as modelled by Saaty (1977) to determine the weights in this thesis's SDG 7 composite index.

According to Saaty (1977), the AHP-method allocates weights through pairwise comparisons. The comparisons are based on notions of importance, i.e. that one parameter is considered to be more, less or equally important to another parameter (Madurai Elavarasan et al., 2022;

OECD, 2008). A potential downside to this method is that notions of importance are subjective, as these are determined by the index constructer (OECD, 2008). If notions of importance are not sufficiently motivated for, they might not reflect reality and create biased index outputs.

However, what is mentioned just above is arguably also one of the strengths of the AHP analysis. All indicators and parameters are potentially not of similar importance for everyone. For example, lack of access to energy might not be considered an issue in Europe (Madurai Elavarasan et al., 2022), but it might in Ghana. Therefore, parameter weights that are universal, i.e. that are used for constructing the SDG 7 composite index for all countries at all times, could result in index outputs that does not efficiently guide countries in their specific energy sustainability challenges.

Due to what is stated above, it is clearly not desirable, or maybe not even possible, to have universal weights to the parameters of the SDG 7 composite index. Using the AHP-method, one can instead generate the weights to the index parameters to fit the current research setting (Madurai Elavarasan et al., 2022). The AHP-method is therefore used to create a SDG 7 composite index that will fit the energy situation in Ghana, which will hopefully also contribute to more efficient policy suggestions.

In practise, the weights are allocated in the following way; From the pairwise comparisons, all parameters are ranked between 1-9. Again, the scaling is based on subjective motivations, were the higher the ranking value, the stronger is the importance of one parameter over the other. This while the value of 1 indicates that the variables are considered to be of equal importance (Saaty, 1977). Saaty's (1977) rankings and what they represent can be seen in Table A5 in the Appendix 4.

Through the pairwise comparisons, the selected parameters form a $n \times n$ matrix. The matrix works in such a way that the element a_{ij} is the reciprocal of element a_{ji} (Saaty, 1977). For example, if parameter A is considered to be slightly more important than parameter B, this would result in parameter A being ranked 3 in comparison with parameter B. This while parameter B is ranked 1/3 when compared with parameter A (OECD, 2008). Weights are then obtained through normalizing the matrices, and the suitability of the weights are then controlled for by calculating the consistency ratio (CR) (Madurai Elavarasan et al., 2008). If the CR is less than 10%, the weights can be considered consistent and sufficient for the given scenario (OECD, 2008).

Weights are determined for all indicators including more than one parameter. This means that weights have been allocated to the parameters of the *Clean Energy*, *Energy Security* and *Energy Accessibility*-indicators. Finally, the individual indicators are also given its own weights, in order to generate the final SDG 7 composite index.

4.4.1. The Clean Energy Indicator

The renewable contribution per capita-, non-renewable contribution per capita- and renewable richness in the final energy mix-parameters are all considered to be of equal importance for the clean energy prevalence of a country. All parameters are therefore allocated equal weight. The *Clean Energy* indicator is therefore generated through summarizing the parameter values, and then dividing these by their amount, i.e. 3.

4.4.2. The Energy Security Indicator

The ranking and the weights of the parameters included in the *Energy Security* indicator can be found in Table 3 below. The reasoning is the following: exports of electricity is considered to be a characteristic of a country that is more secure in terms of energy. This while imports of electricity are considered to imply that a country need imports to satisfy its demand for energy. Arguably, countries have relative control over what they export, while they depend on other countries for imports. Due to this, exports are considered to be more important for energy security than imports. At the same time, higher levels of diversity in the energy mix imply more secure energy systems. This as higher diversity imply that a country is not overly dependent on any one energy source, meaning that contemporary disruptions of any energy source does not impact energy security significantly. However, as access to different energy sources could be impacted by imports, the EDP is ranked as less important than imports. This results in a AHP analysis matrix with the following design;

Table 3: AHP Analysis for the weights of the Energy Security Indicator

AHP Analysis	Pairwise Comparison Matrix				Consistency Test		
	Import per capita	Export per capita	EDP	Weights (W_i)	λ_{max}	CI	CR
Import per capita	1	½	2	0,297	3,009	0,003	0,005
Export per capita	2	1	3	0,539			

EDP	½	⅓	1	0,164

For a proper description of how weights and the CR is calculated can be found in Appendix 5. As CR is found to be 0.005, which is less than 10% (i.e. 0,1), the generated weights are found to be consistent. These are therefore used to construct the *Energy Security* indicator via Equation (6).

$$Energy\ Security\ = \sum_{i=1}^{3} W_i \times x_{it} \qquad (6)$$

The *Energy Security* indicator is in other words the sum of the weights, W_i, multiplied with the corresponding parameter *i* at time *t*.

4.4.3. The Energy Accessibility Indicator

Access to electricity and clean cooking fuels are considered equally important for energy accessibility. The parameters are therefore weighted the same, and the *Energy Accessibility* indicator is generated by dividing the sum of the two parameters by two.

4.4.4. The SDG 7 Composite Index

Table 4 below presents the ranking from pairwise comparisons between the different indicators of the SDG 7 composite index, using the rankings of Madurai Elavarasan et al. (2022). To obtain a table that is easier to read, the indicator names are shortened to abbreviations. In the below tables, CE, CI, ES, EI and EA represents the *Clean Energy*, *Carbon Intensity*, *Energy Security*, *Energy Intensity* respectively *Energy Accessibility*-indicators. From the normalization, I managed to obtain similar weights and outcomes of the consistency test, however not identical as Madurai Elavarasan et al. (2022).

Table 4: AHP Analysis for the Madurai Elavarasan's (2022) weights for the SDG 7 Index

AHP Analysis	Pairwise Comparison Matrix					Weights (W_i)	Consistency Test		
	CE	CI	ES	EI	EA		λ_{max}	CI	CR
CE	1	2	3	3	4	0,395	5,112	0,028	0,025
CI	½	1	2	2	3	0,239			
ES	⅓	½	1	2	3	0,173			
EI	⅓	½	½	1	2	0,120			
EA	¼	⅓	⅓	½	1	0,073			

As the CR again is lower than 10%, the suggested weight is found to be consistent and will be used to construct the SDG 7 composite index of this thesis. The index is therefore aggregated through the sum of each weight with is corresponding indicator, which can also be expressed as;

$$SDG\ 7\ Composite\ Index = \sum_{i=1}^{5} W_i \times I_i \tag{7}$$

From Table 4, one can observe that Madurai Elavarasan et al. (2022) put emphasis on environmental sustainability in their SDG 7 composite index. This as the *Clean Energy* indicator is ranked as the most important indicator, while the second most important indicator is *Carbon Intensity*.

If one were to consider the indicators being more linked to either environmental or social aspects, then substantial more weights is being put on environmentally linked indicators in Madurai Elavarasan et al's (2022) index. This as the aggregated weights of the environmental indicators (*Clean Energy* and *Carbon Intensity*) is 0,634. This while the aggregated weight for the more social indicators (*Energy Security* and *Energy Accessibility*) is 0,246.

Due to the pressing challenges of climate change, and the setting of Madurai Elavarasan et al.'s (2022) paper, the weights in Table 4 might be justified. The authors develop their SDG 7 composite index on European countries, were energy and clean cooking access is found to be almost universal (Madurai Elavarasan et al., 2022). However, in countries where access is not universal, one can question if the suggested ranking and weights are relevant. After all, SDG 7 is not just about generating environmental sustainability to energy systems. Apart from being sustainable and modern, the goals states that energy should also be affordable and reliable (UN, 2023b), which are arguably related to social aspects of sustainability.

To control for this, a second set of weights will used when constructing the SDG 7 composite index. The purpose of the new weights is to balance the environmental and social aspects of the SDG 7 composite index more evenly. In the AHP Analysis to obtain these weights, clean energy is still considered essential and central for sustainable energy systems. Most weight will therefore still be assigned to the *Clean Energy* indicator. *Energy Security* is then found as the most important social indicator. This as secure access to energy is considered vital for the other social indicator, i.e. the *Energy Accessibility* indicator. The *Energy Security* indicator is therefore seen as the second most important indicator in the entire index and is assigned the second to largest weight.

Energy Intensity account for both environmental and social aspects of energy sustainability. This as lower energy intensities are often considered to be aligned with higher levels of economic development (Stern, 2011) and be better for the environment. This indicator is therefore placed in the middle of all the other indicators. After that is the *Energy Accessibility* indicator, due to the importance of energy access for higher standards of living and quality of life. Finally, *Carbon Intensity* is assigned the smallest amount of weight. Although reduction CO2 emissions are essential for obtaining more sustainable energy systems, this aspect is indirectly considered by the *Clean Energy* indicator.

All this results in the AHP analysis presented in Table 5 below. With a consistency ratio lower than 10%, the suggested weights are found suitable for this research. Therefore, this second set of weights will be used to see if these presents a different picture of the energy sustainability performance of a developing country like Ghana.

Table 5: AHP Analysis for the thesis suggested weights for the SDG 7 Index

AHP Analysis	Pairwise Comparison Matrix						Consistency Test		
	CE	ES	EI	EA	CI	Weights (W_i)	λ_{max}	CI	CR
CE	1	2	2	3	3	0,353	5,136	0,034	0,030
ES	½	1	2	3	3	0,267			
EI	½	½	1	2	3	0,188			
EA	⅓	⅓	½	1	2	0,112			
CI	⅓	⅓	⅓	½	1	0,080			

5. *Data*

This part of the thesis provides a description of the sample and data sources used in this thesis, as well how the dataset of this thesis differs from the dataset of Madurai Elavarasan et al.'s (2022) paper. Further, it presents the results of some tests that estimate the suitability of the data to generate a composite index.

5.1. Sample

As mentioned in the Introduction, Ghana has recently been on a development streak and have discovered reserves of oil and gas. To contribute to knowledge of sustainable development, Ghana was chosen as case study to examine how these happenings can affect a country's sustainability performance in terms of energy.

When it comes to sustainable development, it is arguably not only relevant to consider separate points in time. By covering longer periods of time, one could potentially identify change, but also its direction, magnitude and pace. From this, it also becomes possible to make projections for the future. Due to this, I intend to cover as much time as possible in this thesis. Given this, and due to the data that is available, this resulted in a considered period of 20 years ranging between the years of 2000-2019.

5.2. Sources

Multiple parameters are needed to construct the SDG 7 composite index, meaning that data needs to be collected either to present these directly or generate them manually. Which data that was collected, and from where, is presented in Table 6 below. The data is used either in its original form or has been manipulated as described in Section 4.2.2.

Table 6: List of Collected Data & Sources

Parameters	Sources
Total Primary Energy Supply (TPES)	Energy Commission of Ghana, 2020
Share of Renewables in TPES	Energy Commission of Ghana, 2020
Non-renewable Contribution to TPES	Energy Commission of Ghana, 2020
Renewable Contribution to TPES	Energy Commission of Ghana, 2020
Shares of Sources in TPES	Energy Commission of Ghana, 2020

Exports of Electricity	Energy Commission of Ghana, 2020
Imports of Electricity	Energy Commission of Ghana, 2020
Access to Electricity	World Bank, 2023c
Access to Clean Fuels and Techniques for Cooking	World Bank, 2023c
CO2-Emissions	World Bank, 2023c
Energy Intensity	World Bank, 2023c
Population	World Bank, 2023c

As can be seen above, data has been collected on twelve variables, out of which seven are related to the TPES and electricity trade. These are collected from the Energy Commission of Ghana (ECG) (2020), a statutory body to Ghana's president on issues related to energy (ECG, 2023). The data is collected from their *National Energy Statistics 2000-2019* report (ECG, 2020), which was produced in collaboration with the main energy institutions of the country.

The five other variables are on more general aspects of Ghana, although some are also related to energy and/or electricity. Examples are population, CO2-emissions and access to electricity. These are all collected from the World Bank's *World Development Indicators* (2023c).

5.3. Differences in Dataset

There are differences between the dataset of this thesis and the dataset of Madurai Elavarasan et al.'s (2022) paper, which are not related to the aspects of time or considered countries. The differences are instead related to the variables that are included in making the *Energy Security* indicator. In Madurai Elavarasan et al.'s (2022) paper, four variables are included in this indicator. Out of these, only one parameter is included in this thesis - the EDP. The variables that are excluded are the Energy self-sufficiency (ESS) ratio as well as Energy Imports and Exports per capita.

The ESS ratio is explained by Madurai Elavarasan et al. (2022) to describe a country's ability to provide for themselves in terms of energy. A ratio equal to or more than 1 should be interpreted as that the country can provide for their own energy needs, while a ratio below 1 indicate the opposite (Madurai Elavarasan et al., (2022). The ESS ratio in Madurai Elavarasan et al.'s (2022) paper is directly collected from IRENA (2022), but is described as the result of the total production of energy over the total consumption of energy (Madurai Elavarasan et al., 2022). Although I found data on the consumption part (World Bank, 2023c), I did not manage to find data on Ghana's total energy production. This means that I did not have all the necessary data to generate the ESS ratio. No data was found on energy imports respectively exports either, which is why none of these parameters are included in this thesis.

To compensate for the loss of the above-mentioned parameters, I include imports and exports of electricity per capita for Ghana in the *Energy Security* indicator. As stated previously, electricity is not the same thing as energy, but merely a part of it. However, due to this, aspects of electricity security should be able to explain part of the status of energy security, however potentially not the entire picture. Further, as described in Section 2.2.2., Ghana has previously experienced great electricity deficits, caused by the prevalence of Dumsor. This potentially implies that there has existed some sort of insecurity related to electricity in Ghana, and therefore also energy. Further, electricity parameters are used to describe energy parameters in the *Energy Accessibility* indicator with the Access to electricity-parameter, both in this thesis and in Madurai Elavarasan et al.'s (2022) paper. Given all this, I would argue that electricity measures can be suitable proxies for energy, when necessary. This as long as it is motivated for and kept in mind that heating and transport are excluded from the analysis.

The *Energy Security*-indicator of this thesis therefore contains three parameters, out of which two (i.e. EDP and electricity exports) are considered to affect Ghana's energy sustainability in a positive direction. This while the same indicator in Madurai Elavarasan et al.'s (2022) work include four parameters, out of which three (i.e. EDP, ESS and energy exports) is believed to have a positive impact on European energy sustainability. Further, the *Energy Security-indicator* includes one parameter with a negative influence (i.e. imports of electricity respectively energy), both in this thesis and in Madurai Elavarasan et al.'s (2022) paper.

As there is one less parameter which positively influences the *Energy Security*-indicator in this thesis, the impact of the one parameter that have a negative impact on energy security might increase. Due to this, the choice of parameters in this thesis could potentially bias the *Energy Security*-indicator downwards compared to the same indicator in Madurai Elavarasan et al.'s (2022).

5.4. Correlation, Consistency and Suitability

Madurai Elavarasan et al. (2022) analyses the Pearson's correlation coefficient between the index indicators to determine that these in fact measure different aspects of energy sustainability. Acceptable values for the correlation coefficients are considered to be below 0,3 (Madurai Elavarasan et al., 2022). The correlation coefficients between the indicators of this thesis are displayed in Table 7 below. As seen, most indicators are found to be highly correlated, and well above the acceptable value of Madurai Elavarasan et al. (2022).

Table 7: Pearson's Correlation Coefficients, Indicators of the SDG 7 Composite Index

Correlation coefficient	CE	CI	ES	EI	EA
CE	1				
CI	0,8999	1			
ES	-0,3293	-0,4886	1		
EI	-0,9305	-0,9265	0,4345	1	
EA	-0,9277	-0,8984	0,3675	0,8809	1

The high correlation between the different indicators could be because the data covers a period where all indicators experience some sort of development. For example, as will be seen ahead, the *Clean Energy* indicator has experienced a declining trend. This while the indicators *Energy Security*, *Energy Intensity* and *Energy Accessibility* have increased. Similarly, *Carbon Intensity* has gone up as *Clean Energy* have gone down. This is in fact the story the correlation coefficients between the *Clean Energy* indicator and the other indicators tell. Given this, it is arguably not strange that there are high levels of correlation between the different indicators.

Therefore, I chose to proceed with different tests to determine the suitability of the indicators to generate the SDG 7 composite index. First, I check the data's Cronbach Coefficient Alpha (CCA). The CCA is considered meaningful to evaluate when a composite index is the sum of several indicators (OECD, 2008), which is the case in this thesis. The measure evaluates how well multiple variables together describe one concept (OECD, 2008). In the setting of this thesis, the CCA is used to examine how well the indicators together explain energy sustainability. If the CCA results in a value of 0,70 or above, the indicators can be considered consistent and to together describe a concept well (OECD, 2008).

Further, I estimate the Kaiser-Meyer-Olkin (KMO) measure, both for the overall index and its individual indicators. This measure evaluates how suitable the data is for factor analysis. In other words, the KMO measure investigate if the data at hand suits to be summarized from several to fewer variables (Statistics How To, 2023). As the composite index of this thesis is the result from generating one index output out of many variables, this is arguably a relevant measure to examine. While a value of 0,6 is acceptable, values of 0,8 or above is considered 'meritorious' (Kaiser, 1974; OECD, 2008).

The CCA and KMO measures are presented in Table 8 below. The CCA is estimated to 0,897, which is well above the accepted threshold of 0,7. Therefore, the indicators of this thesis's SDG 7 composite index can be considered to together describe the concept of energy sustainability well. Further, KMO-values are examined for the indicators simultaneously and individually. The indicators together reach a value of 0,825, which mean that the data is well-suited for factor analysis.

When examining the KMO-values of the individual indicators, *Carbon Intensity*, *Energy Intensity* and *Energy Accessibility* all obtain values higher than 0,8. These indicators are therefore considered as very suitable for using in a factor analysis. This while the *Clean Energy* and *Energy Security* indicators obtain values of 0,789 respectively 0,778. From Kaiser's (1974) KMO-value classification, these indicators should be considered as 'middling' in their suitability for factor analysis. As these values are close to what is considered the 'meritorious' value (i.e. 0,8), as well as well above the acceptable value (i.e. 0,6) I declare all the considered indicators suitable to together generate the SDG 7 composite index.

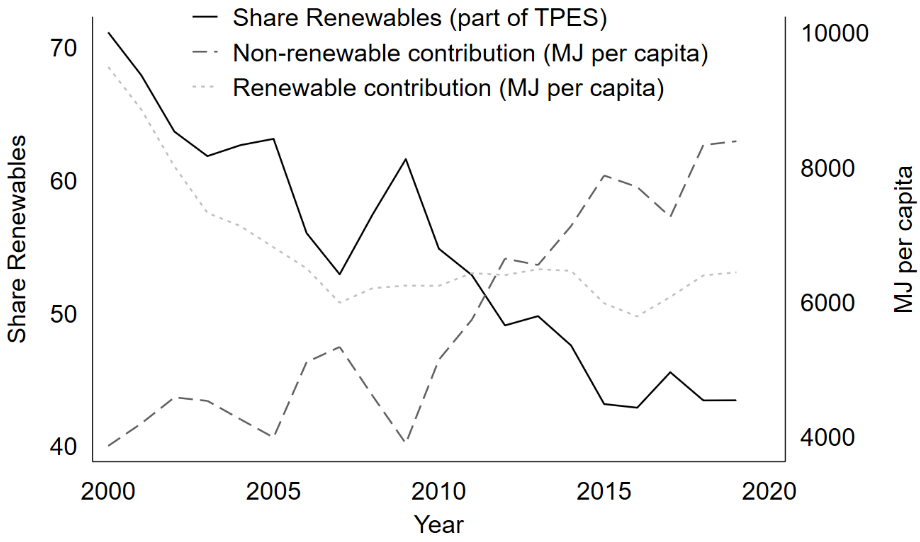
Table 8: Data Consistency & Suitability

	Cronbach Alpha	Kaiser-Meyer-Olkin
Overall:	0,897	0,825
Individual indicators:		
Clean Energy		0,789
Carbon Intensity		0,855
Energy Security		0,778
Energy Intensity		0,824
Energy Accessibility		0,849

6. Results

This part of the thesis contains the results from examining the sustainability performance of Ghana's energy system through the suggested SDG 7 composite index. First, the development of each individual indicator of the index is explained, before revealing the composite index scores these together generate for Ghana. Further, to motivate the existence of the SDG 7 composite index, its scores are compared to the output of an index only considering official SDG 7 parameters. The section is then finalized by presenting the results of an uncertainty analysis.

6.1. Clean Energy Indicator



Graph 6: Share of Renewables in TPES, non-renewable contribution per capita and renewable contribution per capita in Ghana, 2000-2019.

Graph 6 above display the individual performance of each parameter included in the *Clean Energy*-indicator for Ghana. In other words, the above graph shows the developments in shares of renewables in TPES as well as the per capita contribution of non-renewable and renewable energy sources in Ghana between 2000 and 2019. The unit on the left-most y-axis is shares in percentage format. This axis should be considerd for the share of renewables in the TPES parameter, which values are represented by the filled in line. The units on the right-most y-axis is MJ per capita, and should be used when examining the non-renewable and renewable contribution parameters, i.e. the dashed respecticly dotted line above.

Over the considered period, there is a clear declining trend in the share renewables make of TPES. In the year 2000, the rate is approximatly 70%, but ended up around 40% in 2019. This imply that Ghana contiously obtained less energy from renewable energy sources throughout the period. A similar conclusion is drawn when examining the non-renewable contribution per capita parameter, which is continously increasing over the period. In fact, it almost looks like the developments of renewable share of TPES and non-renewable contribution per capita mirrors each other, but in different directions. For example, while there is a sharp decline in non-renewable contribution per capita in 2009, there is a sharp increase in the renewable share of TPES the same year.

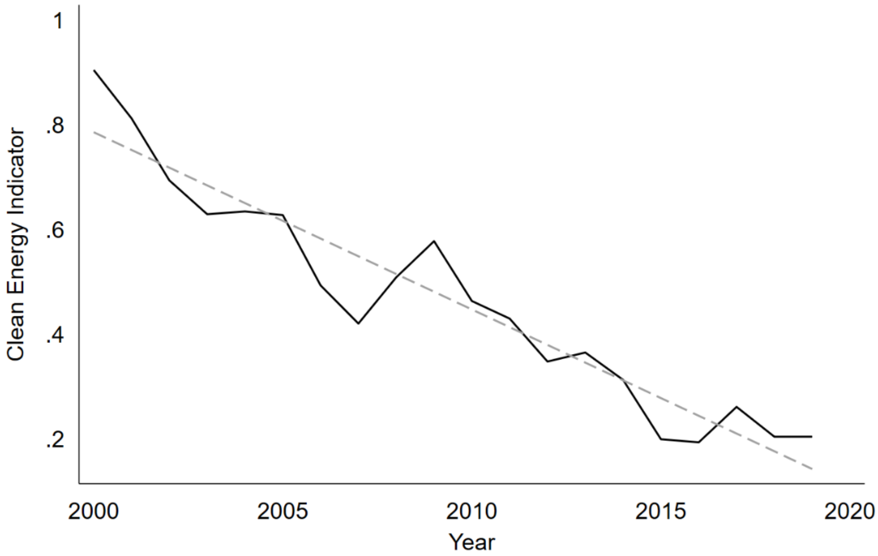
Given this observation, it is intresing that the development of the renewable contribution per capita parameter looks different. Initially, the development of the renewable share in TPES and renewable contribution per capita seem to correlate. This as both parameters continously decline up until 2007/2008. However, from 2009 onwards, renewable per capita contribution remains at a relative similar level for the remains of the period, while renewable share in TPES continous to decline.

A potential explanation to what is discussed above is that the non-renewable sources have grown in Ghana’s energy system, both in relative and absolute terms. This while the energy obtained from renewable sources have not changed that much in absolute terms. Table A6 in Appendix 6 contains an extraction from the thesis’s dataset to show this. From this table, one can see that the total amount of energy obtained from renewable sources increased by approximately 16 000 TJ from 2000 to 2019. In the same period, the total amount of energy steming from non-renewable sources grew by approximately 188 000 TJ.

The increased usage of non-renewable sources, along with a significant population growth (~+12 000 000) results in an growing non-renewable contribution per capita-parameter as well. This while renewable energy extraction declined in the beginning of the period, to then increase above the initial value at the end of it, although not by much. Therefore, the amount of energy stemming from renewable sources is relativly similar throughout the period. Along with the population growth, this results in a renewable energy per capita contribution parameter that first declines, and then remains stable around 6 000 TJ per capita from 2005 and onwards.

Given that the renewable share of TPES and renewable contribution per capita positivly influence the sustainabiliy of an energy system, Ghana’s sustainability performance in terms of clean energy can be expected to decline during the examined periods. From examining Graph

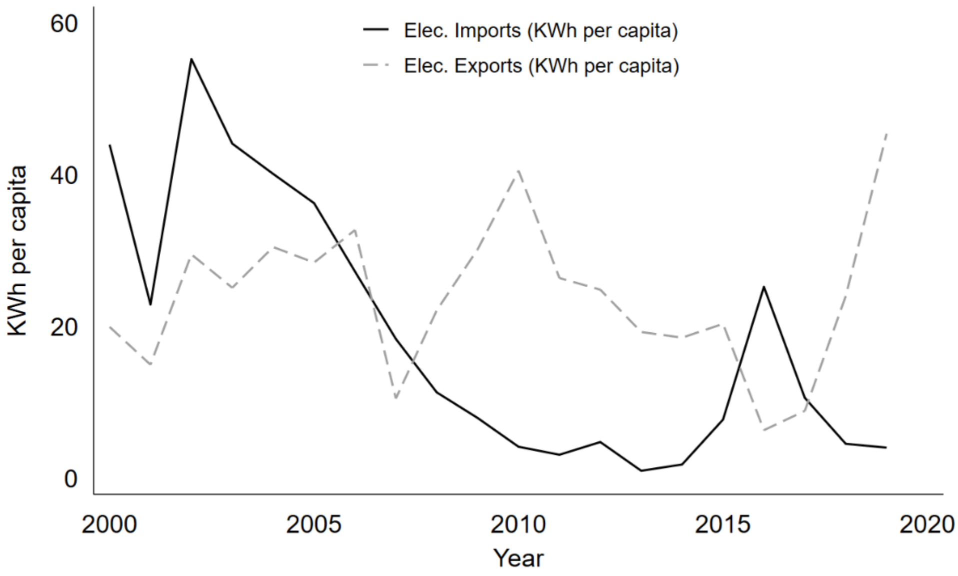
7 below, one can see that this is also the case. The solid line is the score of Ghana on *Clean Energy*-indicator over the examined period, while the dashed line visualizes its trend. In the year 2000, Ghana scored over 0.90, which declined to around 0.20 in 2019. Although the scores should not be interpreted by their absolute values, they do imply a significant and strong decline in sustainability performance in terms of clean energy during the examined period.



Graph 7: Clean Energy Performance of Ghana, 2000-2019.

6.2. Energy Security Indicator

Graph 8 present the development of the parameters related to the per capita trade in electricity. Import values are seen in the solid line while exports are read through the dashed line. Prior to 2008, Ghana imported more electricity than it exported. Arguably, this imply that the energy security of Ghana was lower before 2008. This given that electricity imports are seen as a mean to meet the domestic electricity demand, which would be unmet without the imports. If exports are similarly seen as an indication of a surplus of energy, this would imply that Ghana's energy security have increased from 2009 onwards. This as Ghana exports more electricity than it imports for most years after 2009.

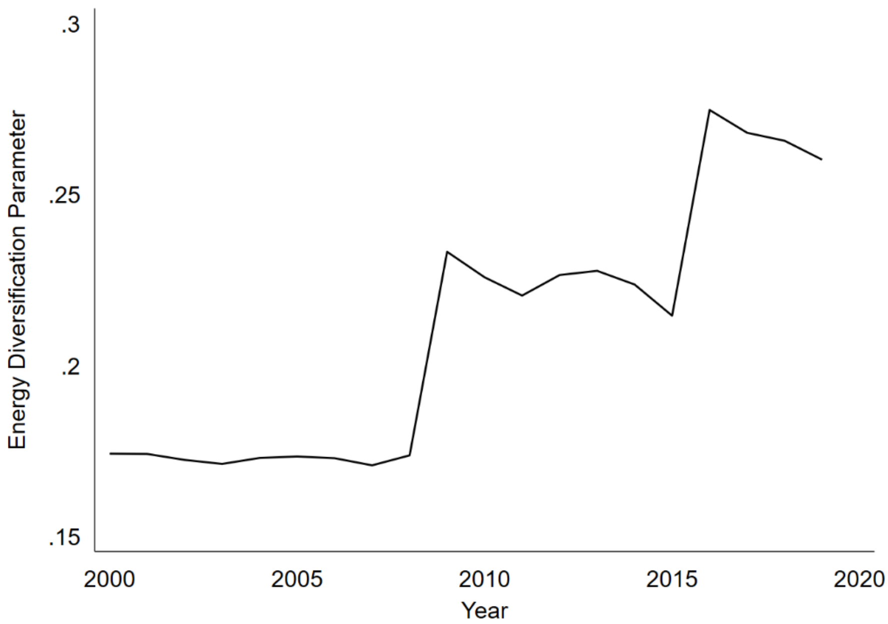


Graph 8: Electricity Trade of Ghana, 2000-2019.

However, the trade curves fluctuate extensively during the examined period. This would imply that Ghana's ability to sufficiently provide for themselves in terms of energy varies between the years, which further indicates that the level of energy security level is still relatively low in the country.

Graph 9 displays the development of the EDP. The purpose of the EDP is to investigate how diversified an energy system is. In this setting, energy security is considered to increase when the number of energy sources are higher. This as a more diversified energy system can be considered less dependent on any one source of energy. Therefore, EDP is calculated by considering the different energy sources of Ghana's TPES, using Equation (1) from Section 4.2.2. The contents of Ghana's TPES, along with the resulting EDP scores, are presented in Table 9 on the next page.

It should be noted that although solar is claimed to make up 0% of TPES during the examined period, this does not mean that the contribution of solar in Ghana's TPES is equal to 0 in absolute terms. As previously mentioned, solar power starts being a part of Ghana's TPES in 2015, but at such low levels that it makes up less than 1% of total TPES during the entire period. This is why solar power is shown to make up 0 percent of Ghana's TPES in Table 9.



Graph 9: Energy Diversification Parameter of Ghana, 2000-2019.

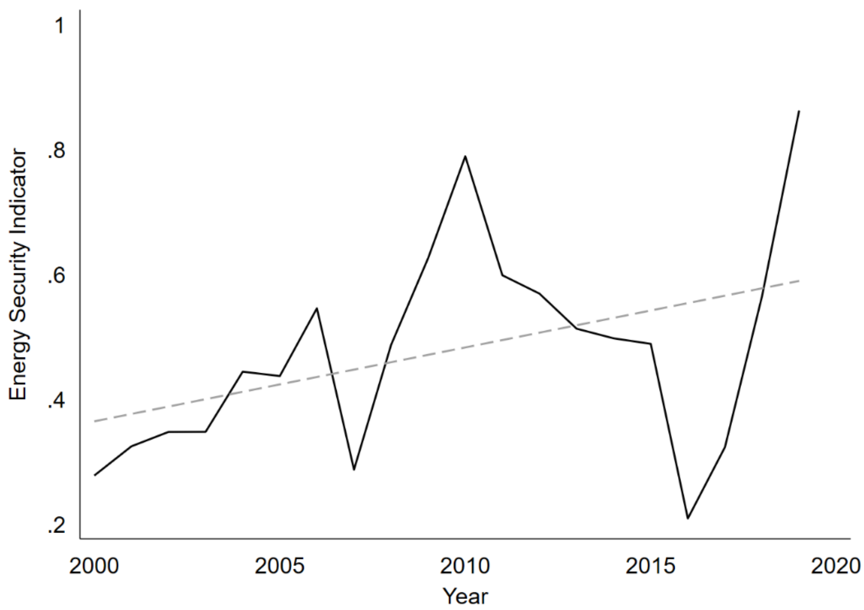
Table 9: Shares in Ghana's Total Primary Energy Supply (TPES) (ECG, 2020)

Year	Gas (%)	Oil (%)	Biomass (%)	Hydro (%)	Solar (%)	EDP
2000	0	28.9	62	9.1	0	0,17425
2001	0	32.1	58.9	9	0	0,17417
2002	0	36.4	56.7	6.9	0	0,17242
2003	0	38.2	56.3	5.5	0	0,17125
2004	0	37.4	55	7.6	0	0,17300
2005	0	36.9	54.7	8.3	0	0,17342
2006	0	44	48.5	7.5	0	0,17292
2007	0	47.1	47.9	5	0	0,17083
2008	0	42.6	48.9	8.5	0	0,17375
2009	0.1	38.4	51.8	9.8	0	0,23322
2010	5.7	39.5	46.2	8.7	0	0,22579
2011	10.1	37.1	44.3	8.5	0	0,22044
2012	4.7	46.3	40.8	8.3	0	0,22644
2013	3.4	46.8	41.5	8.3	0	0,22767
2014	6.8	45.7	39.7	7.9	0	0,22367
2015	12.4	44.5	37.9	5.3	0	0,21457
2016	7.3	49.9	37.8	5	0	0,27467
2017	11.9	42.5	40.5	5	0	0,26800

2018	13.4	43.1	38.6	4.8	0	0,26567
2019	18.2	38.3	37.8	5.6	0	0,26015

As seen above, the diversification of Ghana's energy mix has increased over time. The addons of gas in 2009 and solar power in 2015 show a direct impact in an abruptly increased curve in Graph 9. However, after each sudden increase, the slope of the curve is slightly negative. Potentially this is because the usage of hydropower, which is considered to be a relative secure source of energy, has continuously decreased in the energy mix from 9.1% in 2000 to 5.6% in 2019. This while the dependence of more high-risk energy sources such as gas - from 0 to 18.2% - and oil – from 28.9 - 38.3% - has continuously increased.

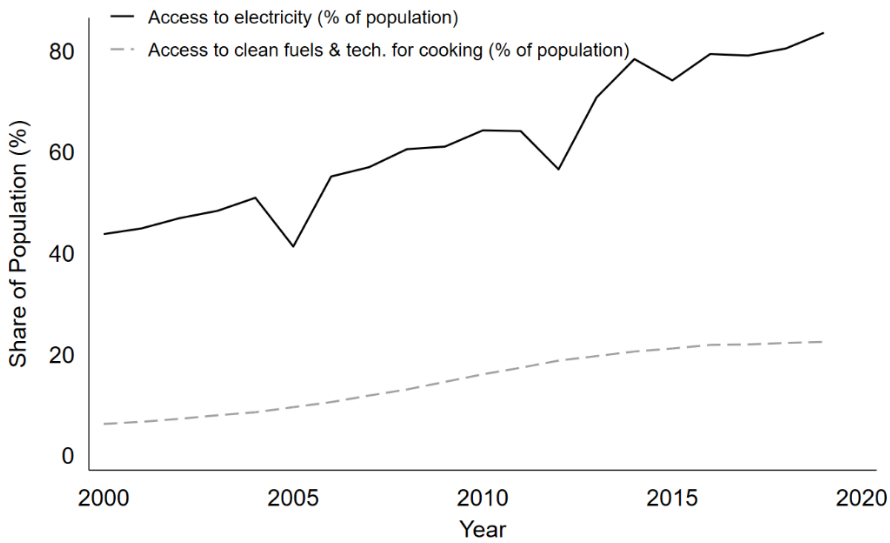
Due to the higher levels of exports and larger diversification of the energy system, there are implications of a positive trend in energy security in Ghana over the considered period. However, due to the fluctuations in electricity trade, the improvement might not be overly consistent nor strong. Arguably, this is what is seen in Graph 10 below. There are great fluctuations in the scores on the *Energy Security* indicator between the years, represented by the filled in line. This while the trend, shown by the dashed line, remains positive throughout the period. However, as high-energy security is vital for a sustainable energy system, this development is regarded as overall positive for a more sustainable energy system in Ghana.



Graph 10: Energy Security performance of Ghana, 2000-2019.

6.3. *Energy Accessibility Indicator*

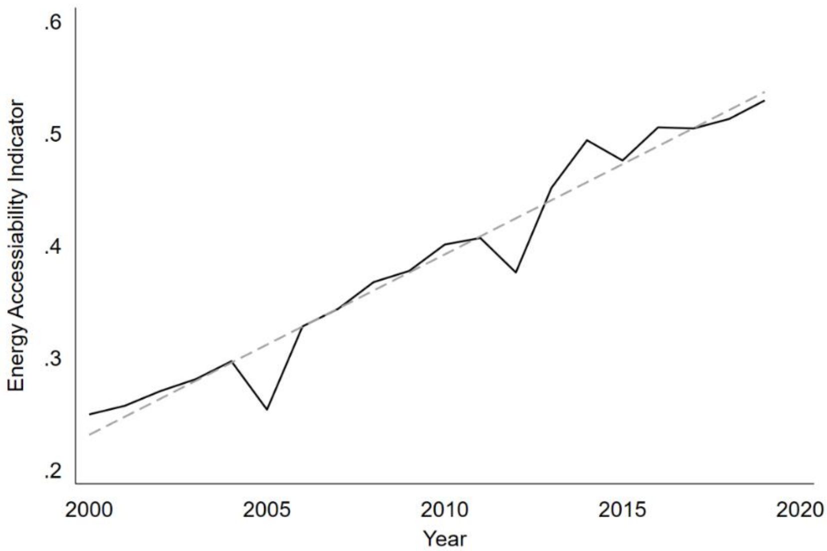
In Graph 11 below, the y-axis is shares of the population in percentage format. This while access to electricity is visualized by the solid line and access to clean fuels and technologies for cooking is represented by the dashed line. During the examined period, the amount of people with access to electricity more than doubled. This as in the beginning, around 40% of Ghana's population had access to electricity, which grew to above 80% at the end of the period. This while access to clean fuels and technologies for cooking grew from around 6% to 22%, which is an increase of almost three times the initial value. Given that there has been a significant increase in population during the same period, the increase of both access-parameters implies that there is a positive trend in terms of energy accessibility in Ghana.



Graph 11: Access to Energy and Clean Cooking Fuels in Ghana, 2000-2019.

In both 2005 and 2012 there are sudden declines in the access to electricity curve. The decline in 2012 could potentially be explained by that this year was the start of one of the most recent Dumsor-periods in Ghana, i.e. periods of electricity crisis. However, as 2005 is not considered to have been part of any Dumsor-period (Kumi, 2020), this explanation does not fit for the decline seen that year.

Given the positive trends in the access-parameters, and that these are weighted equally, the overall trend in the *Energy Accessibility*-indicator should also be positive. This type of development is also observed in Graph 12. Over the examined period, Ghana's has experienced a significant improvement in terms of energy accessibility, which is considered to contribute positively to a more sustainable energy system.

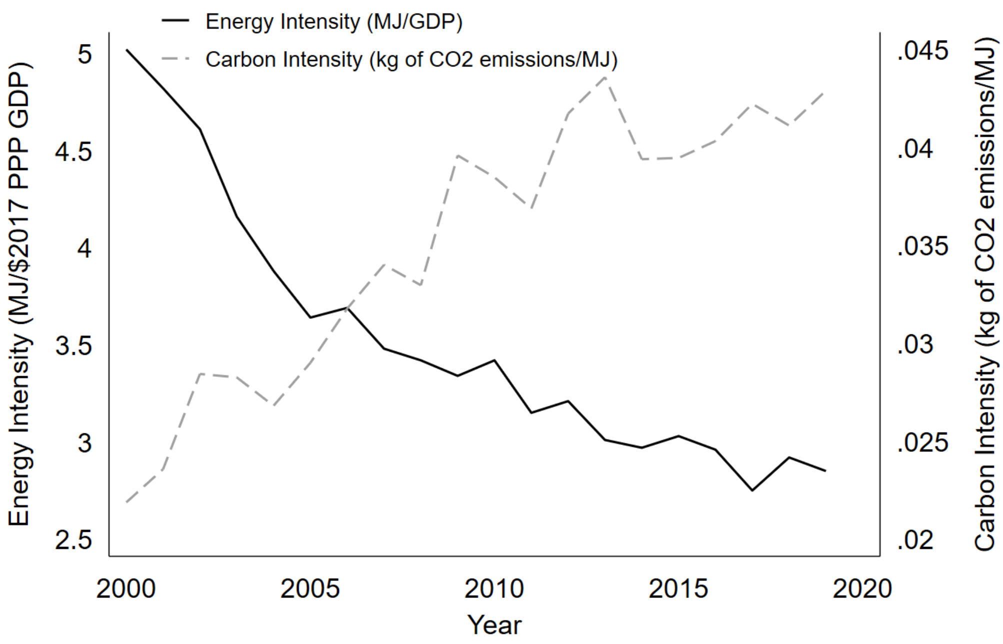


Graph 12: Energy Accessibility performance in Ghana, 2000-2019.

6.4. *Carbon & Energy Intensity Indicators*

Both increased carbon- and energy intensity is considered to be negative in terms of sustainability. This as increased energy intensity implies that more energy is needed to produce a given value of goods and/or services. The less energy that is needed, the more energy efficient can a production be considered to be, and therefore also more sustainable. This while higher carbon intensty implies that the energy system uses fossil fuels more extensivly, which is negative out of a sustainability perspective.

The development of the carbon- and energy intesnities of Ghana is displayed in Graph 13 below. On the left-most y-axis is a mesure of MJ per unit of GDP, which is measured as purshasing power parity of 1 US Dollar of 2017's value ($2017). This axis is linked to the filled in line, which represent the energy intesnity-parameter. This while the right-most y-axis measures carbon intensities, in terms of kg of CO2 emissions per unit of energy. represented by the dashed line.



Graph 13: Performance in Energy Intensity & Carbon Intensity in Ghana, 2000-2019.

In terms of energy intensity, Ghana's energy system seems to have become more sustainable over the period. This as energy intensities are continuously decreasing, meaning that Ghana is becoming more energy efficient. This is in line with the idea that economies tend to become more energy efficient as they develop (Stern, 2011). However, in terms of carbon intensities, Ghana seems to have moved in a less desirable direction. This as carbon intensities continuously have increased over the considered period, which imply that Ghana's energy system has become dependent more on fossil fuels.

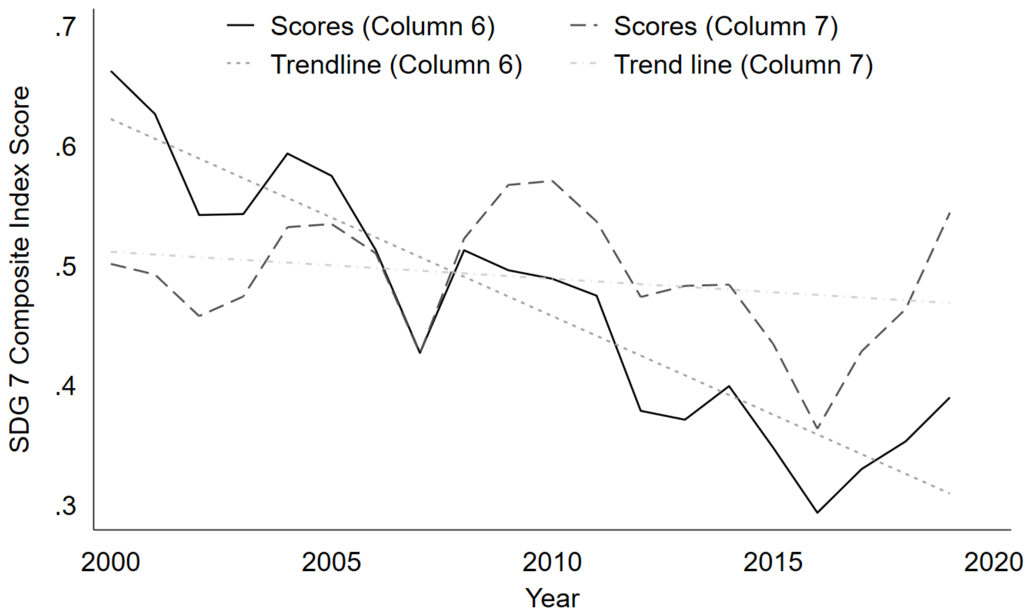
6.5. *SDG 7 Composite Index*

Given the discussions in the above subsections, it would seem like Ghana's energy system has experienced both positive and negative developments in terms of sustainability. This as the prevalence of clean energy has declined and carbon intensities have increased, which is signs of an unsustainable development. At the same time, energy security, intensity and accessibility have all increased, which are positive signs for improved energy sustainability.

Considering this, it is not necessarily easy to determine in which direction the overall sustainability performance of Ghana's energy system has gone. When using weights that emphasizes environmental aspects, such as the weights suggested by Madurai Elavarasan et al. (2022), one can expect a negative development in terms of energy sustainability in Ghana. However, the weights suggested by this thesis is arguably more balanced between environmental and social aspects of sustainability. Therefore, the question is how this weight system affects the results in in terms of overall sustainability performance.

In Table A7 in Appendix 7, the indicator scores at different years are presented, along with the SDG 7 composite scores these together generate. Column (6) presents the composite score obtained using Madurai Elavarasan et al.'s (2022) weights. As expected, these scores imply a significant, negative trend in Ghana's energy sustainability performance. This as in the composite index score is 0,662 in the year 2000, while it is 0,390 in 2019. The development of these scores are displayed in Graph 9 by the filled in line. This while its trend is represented by the dotted line.

In Column (7) is the composite scores obtained using the weights suggested by this thesis. Considering these scores, a slightly different story is told than when Madurai Elavarasan's weights are used. The overall trend is still negative, but the index scores range around 0,500 for the entire period. The scores are represented by the dashed line in Graph 14, while the trend is displayed by the dashed-dotted line.



Graph 14: SDG 7 Composite Index Scores of Ghana, 2000-2019.

Again, the values of the composite index and its indicators should not be interpreted by their absolute values, but rather about the trend they imply. Both composite indices imply that the overall sustainability performance of Ghana's energy system has declined over the considered period, although at different strengths. This as the negative trend is clearly stronger when Madurai Elavarasan et al.'s (2022) weights are used.

6.6. Sensitivity Analysis

To assess the quality of the theory and models behind a composite index, one performs sensitivity analysis. Through such an analysis, one examines the variation in the output when something is changed in the input (OECD, 2008). In line with Madurai Elavarasan et al. (2022), the choice of sensitivity analysis related to indicator exclusion. This means that one indicator is excluded at a time during different weightage scenarios. The effect of removing an indicator is estimated as the average of the sum of the differences between the composite index value and the index value obtained when an indicator is excluded. The differences are considered in their absolute format, and the average is calculated over time. Mathematically, this is expressed in equation (8);

$$Average\ Influence\ of\ Excluded\ Indicator = \frac{1}{T}\sum_{i=1}^{T}\left|(Score)_{ref,t} - (Score)_t\right| \qquad (8)$$

In this formula, $(Score)_{ref,t}$ is the composite index score of time t, while $(Score)_t$ is the score obtained by excluding an indicator.

The considered weightage scenarios are the suggested weights of Madurai Elavarasan et al. (2022), the suggested weights from this thesis as well as an equal weightage situation. In each of the scenarios, one indicator is removed at the time, resulting in five different indicator combinations per weightage scenario. As the weights of the indicators are obtained through an AHP analysis based on including five indicators, a new AHP analysis needs to be performed for each indicator that is removed. This in order to obtain a new set of appropriate weights (OECD, 2008). As all of the obtained weights resulted in a consistency ratio smaller than 10%, the obtained weights were found consistent and found fit for this sensitivity analysis. All the weights and their consistency ratio (CR) can be seen in Table A8 in Appendix 8.

The average effect of removing each indicator in all three weightage scenarios are shown in Figure 2 below. The hight of the bar represent the influence of the indicator on the index value. This means that the higher the bar, the more influence is the excluded indicator considered to have. Again, the indicators names are shown in abbreviations. This means that CE, ES, EI, EA and CI represents the *Clean Energy*, *Energy Security*, *Energy Intensity*, *Energy Accessibility* respectively *Carbon Intensity*-indicators.

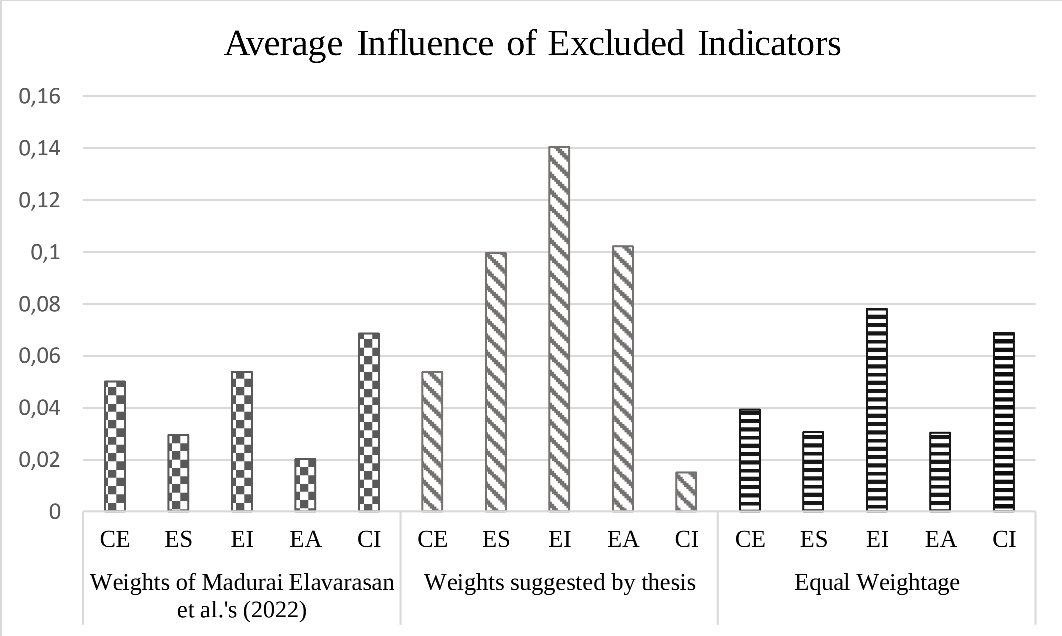


Figure 2: Sensitivity Analysis – Excluded Indicator Influence

The indicator that has the most similar influence across all weightage scenarios is the *Clean Energy* indicator. Its influence is estimated to be the highest in the scenario with the suggested weightage of this thesis, and the lowest in the equal weightage scenario. Further, the indicator that is estimated to have the largest influence on the index in the scenario with the thesis-suggested weights is *Energy Intensity*. After that, the falling order of influence is *Energy Accessibility*, *Energy Security*, *Clean Energy* and *Carbon Intensity*.

The estimated indicator influence is the most similar between Madurai Elavarasan et al.'s (2022) weightage- and the equal weightage scenarios. The order of most to least influence for the Madurai Elavarasan et al.'s (2022) weights go from *Carbon Intensity*, *Energy Intensity*, *Clean Energy*, *Energy Security* and *Energy Accessibility*. For the equal weightage scenario, the ranking goes from *Energy Intensity*, *Carbon Intensity*, *Clean Energy*, *Energy Security* to *Energy Accessibility*.

In their sensitivity analysis, Madurai Elavarasan et al. (2022) find that the *Clean Energy* and *Carbon Intensity* indicators had higher influence in the index using their suggested weights. This while the equal weightage situation estimated that *Energy Accessibility* was the indicator with the highest influence. Madurai Elavarasan et al. (2022, p.21) argue that this motivates the usage of their weights, as "… clean energy penetration, energy security, and emissions are the biggest existing problems compared to energy accessibility.". In other words, the equal weightage scenario was considered to overestimate the importance of certain indicators which was not considered be aligned with reality (Madurai Elavarasan et al., 2022).

Using a similar logic, I would argue that the weights suggested by this thesis are the most suitable for generating a SDG 7 composite index for Ghana. This due to multiple reasons. For one, Ghana has had severe issues related to energy access due to the Dumsor-crisis. Therefore, security is arguably a very relevant aspects of Ghana's energy system, and worth putting emphasis on.

Second, energy accessibility is not universal, either on the African continent (Hafner et al., 2018) nor in Ghana. Access to energy is an essential part of SDG 7 (UNEP, 2023) and considered vital for human prosperity (Bilgen, 2014; Rosen, 2009; Smith et al., 2013). Therefore, energy accessibility is arguably more relevant to consider for developing countries such as Ghana, rather than in Europe where access is almost universal (Madurai Elavarasan et al., 2022). Finally, energy intensity also a clear goal of SDG 7 (UNEP, 2023). Further, it is the only indicator that gives implications of both environmental and social sustainability. This as lower energy intensity can be considered better for the environment, while higher energy efficiency occurs in more developed economies (Stern, 2011). Therefore, this is also an important indicator of a country's energy system, and of value to emphasize.

As the scenario using the suggested weights of this thesis emphasises all the above-mentioned aspects, I would argue that is motivates the usage of these. Further, this weightage scenario out of the three is also the one estimating the highest influence of the *Clean Energy* indicator. This weightage scenario is therefore also the one that values the *Clean Energy* indicator the most. A potential downside with this weightage scenario is that estimates the lowest influence of the *Carbon Intensity* indicator. This is likely due to the overall lower weightage carbon intensity is given in this weighting scenario.

6.7. Comparison with an 'official' SDG 7 Index

One of the major arguments of this thesis is that the official targets and indicators of SDG 7 are not sufficient to get a proper picture of a country's energy-related sustainability performance. Given this, the SDG 7 composite index is proposed as a more appropriate measure to evaluate countries process towards ensuring access to affordable, reliable, sustainable and modern energy for all.

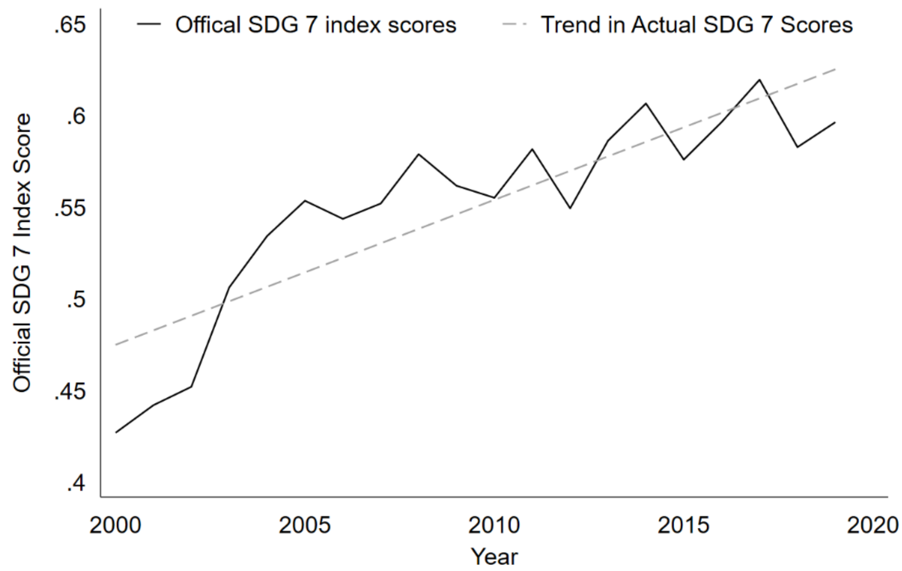
To claim that this truly is the case, I will now compare the output of the SDG 7 composite index with the output of an index including only official SDG 7 parameters. If the index outputs are relatively similar, then the above argument clearly does not hold. This because similar outputs would imply that the different indices indeed measure energy sustainability and evaluate the sustainability performance of countries energy systems similarly. In that case, there would be no contribution of the SDG 7 composite index, and the index with official targets and indicators can be considered to sufficiently monitor the process towards achieving the goal. However, if there is a difference in the index output, then the SDG 7 composite index does provide contribution and insights on the debate of energy sustainability, which motivates its existence and usage.

Due to data availability, the 'official' SDG 7 index include the indicators *Energy Accessibility* (EA)*, Energy Intensity* (EI) and *Renewable Share in TFEC* (RS-TFEC) (Madurai Elavarasan et al., 2022; UNEP, 2023). The first and second indicators are the same as in the suggested SDG 7 composite index. However, the third indicator is not, so data for this indicator is collected from the *World Development Indicators* (World Bank, 2023c). As the renewable share of TFEC is already presented in percentage, this indicator did not have to be normalized. The indicators were then aggregated as the composite index suggested by this thesis, using weights obtained from the AHP analysis presented below in Table 10. As the CR is lower than 10%, the weight was deemed consistent and feasible in this research setting.

Table 10 - AHP Analysis for the Official SDG 7 Index

AHP Analysis	Pairwise Comparison Matrix				Consistency Test		
	EA	RS-TFEC	EI	Weights (W_i)	λ_{max}	CI	CR
EA	1	⅓	½	0,164	3,009	0,005	0,008
RS-TFEC	3	1	2	0,539			
EI	2	½	1	0,297			

The development of the offical SDG 7 index over time for Ghana is displayed in by the solid line in Graph 15 below, while its trend represented by the dashed line. Compared to the main results of this thesis, a different picture of Ghana in terms of energy sustainability is given with this index. In the year of 2000, Ghana's energy system obtained a score of 0,427, which grew to 0,596 by the year 2019. Therefore, the offical SDG 7 index indicate that Ghana's energy system has become more sustainable during the examined period, and that Ghana is experiencing overall improvements in terms of energy sustainability. This without considering aspects of emissions, amount of non-renewnable energy consumption or energy security.



Graph 15: 'Official' SDG 7 Index Scores of Ghana, 2000-2019.

In Table A9 in Appendix 9, Column (1), (2) and (3) represent the index outcomes of the 'official' SDG 7 index, the composite index using the weights of Madurai Elavarasan et al. (2022) respectively the composite index using the weights suggested by this thesis. This while column (4) displays the difference between the composite index with Madurai Elavarasan et al.'s (2022) weights and the actual SDG 7 index. Up until 2005, the SDG 7 composite index give Ghana's energy system a higher score than the official SDG 7 index. This means that before 2005, the SDG 7 composite index found Ghana's energy system to be more sustainable than the official SDG 7 index did. However, from 2005 onwards, the official SDG 7 index scores Ghana higher than the composite index, and the difference between the scores increase with time.

Column (5) represents the difference between the composite index using the weights suggested by this thesis and the official SDG 7 index. The composite index score is higher between the periods of 2000-2002 and 2009-2010. During the rest of the years, the scores of the official SDG 7 scores are higher. Overall, the difference between the composite index using the thesis-suggested weights and the actual index is smaller than the difference between the composite index with the weights of Madurai Elavarasan et al. (2022) and the official index.

The higher scores of the official SDG 7 index are arguably due to that two out of the three indicators have experienced a positive development in terms of sustainability. That is, over the examined period, there has been a significant increase in *Energy Accessibility* in Ghana, while *Energy Intensity* has gone down in the country. These sustainability improvements might balance out the negative performance in the renewable share in Ghana's TFEC, which results in a positive trend in the index.

The composite indices include more sustainability aspects than the official index by considering five indicators instead of three. Arguably, this provides a more comprehensive picture of Ghana's energy performance as more aspects are considered. Further, it implies that only examining the renewable contribution to the energy system neglects the negative impacts the non-renewable contribution has. As the composite indices consider the contributions of all energy sources, they also provide a more comprehensive picture out of an environmental perspective. Therefore, the SDG 7 composite index clearly brings its contributions, which motivates its existence and usage.

6.8. Uncertainty Analysis

Composite indices usually examine multiple subjects (e.g. countries, cities). Through an uncertainty analysis, a composite index gets tested in its consistency in ranking these subjects. This is usually done through testing different ways to normalize, weight and/or aggregate the indicators. The purpose of an uncertainty analysis is therefore to check if an index ranks the performance of a subject similarly when methodological aspects change. Important to note here is that it is not necessarily the output value of the index per say that should be similar, but that the ranking of the different subjects is. This to evaluate if the index is consistent in its evaluation of the performance of the subjects (OECD, 2008).

As this thesis only has one country, it is not possible to rank its performance against that of other countries. Therefore, the uncertainty analysis has to be performed on Ghana's own performance over time. The test will check what causes the largest sources of uncertainty in the suggested composite index – different weightage scenarios or aggregation methods. This test is inspired by Madurai Elavarasan et al. (2022), which considers in total three uncertainty tests. There are mainly two reasons for only conducting one uncertainty test for this thesis. One is that the other tests performed by Madurai Elavarasan et al. (2022) is related to outlier treatment. As this thesis does not consider any specific outliers, these tests were not considered relevant.

Second, given the time and work burden of this thesis, one test was considered what was feasible.

Table 11 below displays the different weightage scenarios that are considered. As seen, there is an equal weightage scenario (W1), while the suggested weight of this thesis are found in the second weightage scenario (W2). The rest of the scenarios are the same suggested ones, but switched between the indicators. In terms of aggregation method, the index output will be compared using a linear method – the one suggested by the thesis – and a geometric method. The geometric aggregation method generates a composite index that is the product of the indicators powered by their weights. This can be summarized in the following mathematical formula:

$$CI_t = \prod I_t^{w_I} \tag{9}$$

Table 11: Different Weightage Scenarios - Uncertainty Analysis

Indicators	W1	W2	W3	W4	W5	W6
CE	0,2	0,3527	0,2672	0,2672	0,2672	0,2672
ES	0,2	0,2672	0,3527	0,1879	0,1879	0,1879
EI	0,2	0,1879	0,1879	0,3527	0,1125	0,1125
EA	0,2	0,1125	0,1125	0,1125	0,3527	0,0796
CI	0,2	0,0796	0,0796	0,0796	0,0796	0,3527

The average differences between the composite index output are listed in Table 12 below. This while the output for all weightage scenarios and aggregation methods can be seen in Table A10 in Appendix 10. As seen in Table 12, the largest difference in output averages occur when the highest weightage it put on the *Carbon Intensity* indicator. This is the case when using both the linear- and geometric aggregation method. Therefore, the score of the SDG 7 composite index is somewhat sensitive to different weightage scenarios. Overall, the differences in averages are smaller when the linear aggregation method is used, compared to when the geometric aggregation method is used. This implies that the index output is more sensitive towards changes in aggregation method, rather than changes in weights.

Table 12: Average differences, Uncertainty test

	Linear Aggregation				
	W1	W3	W4	W5	W6
	0,0196	0,0206	0,0580	0,0371	0,0919

Geometric Aggregation					
W1	W2	W3	W4	W5	W6
0,1189	0,0959	0,0916	0,0828	0,1209	0,1526

However, when examining Table A10, it becomes clear that the geometric aggregation method is unfit to generate this thesis's composite index. This as the composite index output is returned as 0 for two years – the years of 2000 and 2013. The explanation to this lies in Equation (9) above. In the year 2000, the *Energy Intensity* value is its highest value, which results in a normalised value equal to 0. This explains why the index output value is equal to 0 that year, as the product of something multiplied with 0 also is 0. Similarly, 2013 is the year the normalized *Carbon Intensity* is equal to 0, which again turns the entire index score equal to 0.

7. *Discussion*

The results imply is that Ghana's energy system has become more sustainable in some aspects, but not in others. A divide can be seen between environmental and social aspects of sustainability, where the former has seen more improvements than the later. This as the accessibility and security parameters have shown sustainability progress, while the performance of the clean energy and carbon intensity parameters have declined.

In other words - fossil fuel usage in Ghana have extensively increased simultaneously as social welfare and economic development. Of course, this is a mere correlation, and this thesis will not dig into the investigation further where the causation lies. However, Ghana's recent development journey is arguably heavily related to energy resources. This as Ghana's oil and gas resources are considered to have contributed to lift the country from low- to a lower-middle income-country status (Edmond, 2019; World Bank, 2021).

This implies that the growth and development in Ghana, just as in many currently developed nations, have occurred with the help of fossil fuels. Arguably, this further indicate that Ghana has not been able to leapfrog to more sustainable practices in terms of energy. Instead, a dilemma can potentially be seen in the relationship between development, sustainability and energy for developing countries. For one reason or another, renewable energy extraction does not seem to go together with rapid, social development. This implies further that if a country wishes to achieve relatively quick improvement in living standards and growth, fossil fuels seem to be the way to go.

There could be multiple reasons to why fossil fuels are the preferred energy source for development. Examples of such could be price, accessibility, or simply lack of alternatives. As previously mentioned, renewable energy sources have not extensively spread in the Ghanian energy system, nor on the African continent (Hafner et al., 2018). Further, the expansion of renewable energies is hindered by multiple aspects, such as inefficient policies and lack of funding (Kabir Aliyo et al., 2018).

The two sides in the above dilemma would be to either use fossil fuels and obtain social sustainability more rapidly, or put more time and effort into developing sufficient amount of renewable energy sources and reach the same level of social sustainability more slowly. Which side of the dilemma that is more desirable from a sustainability perspective clearly depends on the stance of the reader. It is up to every country to decide which sustainability challenges they find to be more urgent and take action in that direction. However, countries need to know what they choose between, and take sufficient action to deal with potential consequences.

Given this, and keeping the results of this thesis in mind, it would seem that Ghana has chosen the more rapid, but less environmentally friendly, development path. To obtain a more sustainable energy system, the country should plan to improve their renewable energy extraction and reduce their emissions. Further, in a world which aims to remove its dependence on fossil fuels in the future, building an economy with its base in these kinds of resources is arguably not sustainable in the long run. Therefore, it could be of value to put in resources to diversify the country's economy and expand its non-fossil fuel sectors. Although fossil fuels have helped to develop the Ghanaian economy, it can potentially assist it in growing out of depending on them.

Further, even if Ghana's energy systems seem to have become more socially sustainable over the examined period, the country has a way to go to fully achieve even the social parts of SDG 7. Although the share of Ghana's population who has access to electricity have greatly increased during the period, this access is still not universal. Further, a vast majority of Ghana's population do not yet have access to clean fuels and technologies for cooking, and there is still room for improvements in terms of energy security.

8. Conclusion

The purpose of this thesis is to examine how Ghana's energy system has developed over time out of a sustainability perspective. To fulfil this purpose, an SDG 7 composite index was generated to answer the following research question - Has Ghana's energy system become more or less sustainable in the period 2000-2019?

Over the examined period, Ghana's energy system indicated improvements in *Energy Accessibility* and *Security*, which are considered to be more related to social aspects of energy. Further, energy intensities have gone down, which imply that energy efficiencies have gone up. As energy efficiency has been found to increase as a country develops (Stern, 2011), the declining trend in energy intensities could be due to the overall development of Ghana as a country. Further, the increasing accessibility and security related to energy could potentially also be the result of Ghana's recent development streak. All this implies that Ghana has been successful in making its energy system more socially sustainable during the period.

However, the social progress has arguably had an environmental price. This as the usage of fossil fuels have increased, both in absolute and relative terms, and carbon intensities have gone up. These developments have made Ghana's energy system less environmentally sustainable over time, and is likely responsible for the overall negative trend seen in the SDG 7 composite indices.

The development of Ghana's SDG 7 composite index scores was more strongly negative when emphasis was put on environmental aspects. This became clear when comparing the index scores using different weights. Arguably, this imply that the score of the SDG 7 index is highly influenced by the weights that are assigned to each indicator. SDG 7 consists of multiple aspects of energy sustainability, and not just environmentally ones. The goal is set to ensure affordable and reliable, but also sustainable and modern, energy for all (UNEP, 2023). Therefore, the social aspects of energy are arguably an important part of SDG 7, and progress on these are also important to highlight.

Although all countries of the world share the same energy related sustainability challenges, these are potentially more or less stressing in different countries. Further, different countries have made varied amount of progress in making their energy systems more sustainable, have different amount of work left to do to achieve SDG 7 and arguably different possibilities in doing so. As Ghana is yet to achieve universal access to energy and higher levels of energy security, it is of relevance to emphasize the social- as well as environmental aspects of the country's energy system in the SDG 7 composite index. Indices that focus primarily on environmental aspects, by for example using the weights suggested by Madurai Elavarasan et al. (2022), are potentially not relevant for a country like Ghana. Therefore, the weights of Madurai Elavarasan et al. (2022) could be relevant for Europe, which emits higher amounts of emissions and have almost universal access to electricity.

However, for further development of the SDG 7 composite index, I would suggest different weighting schemes for different types of countries. This to fully capture the relevant progress, issues, and trends for the considered country in terms of increasing their energy-related sustainability. Examples of what weights schemes could be based on are geography – e.g. continents or regions – or World Bank income classification (e.g. one type of weights for high income countries, another type of weights for upper middle income countries etc).

Another important finding of this thesis is the 'official' SDG 7 index scores Ghana differently than the composite index. In fact, the index containing official SDG 7 indicators found Ghana's energy system to become more sustainable over time – the opposite of what was concluded using the SDG 7 composite indices. This implies that the current indicators of SDG 7 might not be sufficient to provide guidance for countries in obtaining a more sustainable energy system. In fact, in the case of Ghana, using the official indicators might even be misleading, which could have tremendous consequences in the longer run.

In terms of policy implication on the case of Ghana, the country should maintain their work in generating increased energy access and security, but via more environmentally friendly ways. This in order to fully achieve SDG 7 and overall energy sustainability. This could be done by expanding the energy and electricity generated from renewables, in terms of for example solar- and wind power. However, there are multiple challenges related to this, for example in terms of financing and infrastructure development.

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Appendix

Appendix 1.

Table A1: Creation of Parameters

Indicator	Parameters *(Measure)*	Generation
Clean Energy	Per capita non-Renewable Contribution *(MJ per capita)*	Total non-renewable energy in TPES (MJ) / Population
	Per capita Renewable Contribution *(MJ per capita)*	Total renewable energy in TPES (MJ) / Population
	Renewable Share in TPES *(% of total TPES)*	Total renewable energy in TPES (TJ) / Total TPES (TJ)
Energy Security	Energy Diversification Parameter (EDP) *(EDP Score)*	See formula, Section 4.2.2.
	Exports of Electricity per capita *(KWh per captia)*	Total exported electricity (KWh) / Population
	Imports of Electricity per capita *(KWh per captia)*	Total imported electricity (KWh) / Population
Energy Intensity	Energy Intensity *(MJ per $2017 (PPP GDP))*	Directly from source.
Energy Accessibility	Access to Electricity *(% of total population)*	Directly from source.
	Access to Clean Fuels and Techniques for Cooking *(% of population)*	Directly from source.
Carbon Intensity	Carbon Intensity *(kg of CO2 emissions per MJ)*	Total CO2 Emissions (kg) / Total TPES (MJ)

Appendix 2.

Madurai Elavarasan et al. (2022) consider outliers to be values that are above or below the value of two standard deviations of each parameter. To examine if there were any outliers in the parameter data of this thesis, the same method was used. These outlier tests are visualized in the below figures. Values are represented by the black dots, while the grey fields represent the area in which values are not considered to be outliers. This imples that values outside the grey area is an outlier.

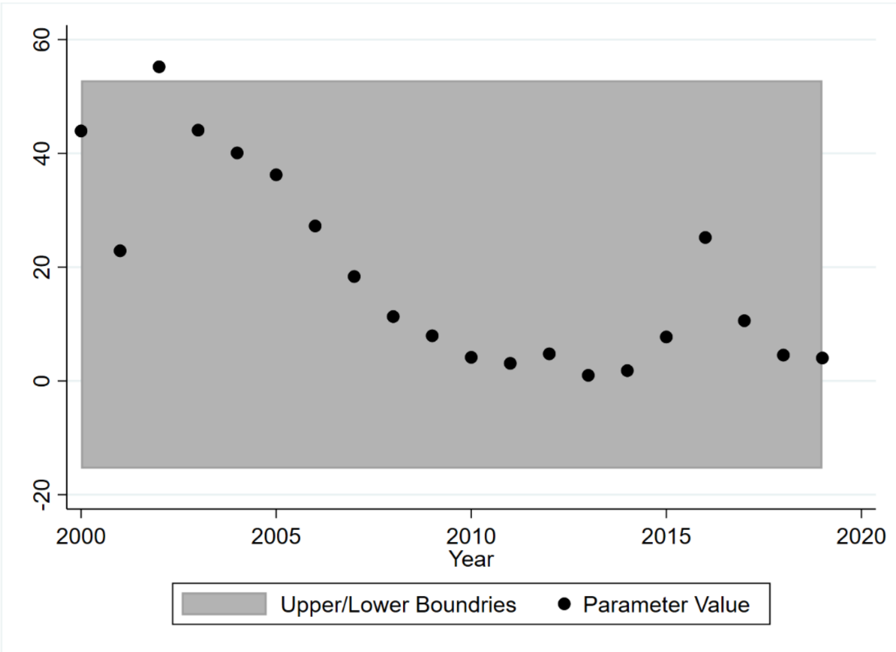

Figure A2.1: Outlier Check in the Imports per capita Parameter

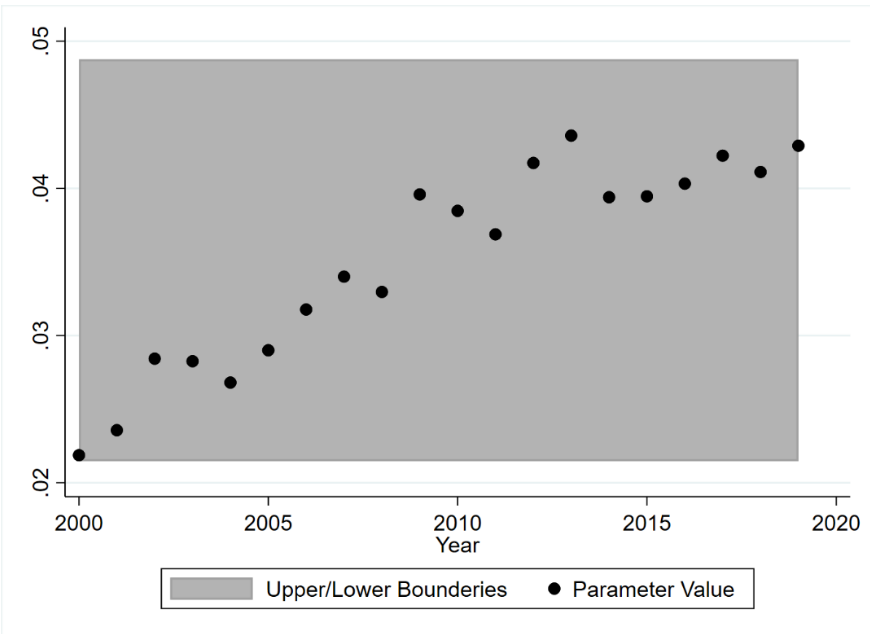

Figure A2.2: Outlier Check in the Carbon Intensity Parameter

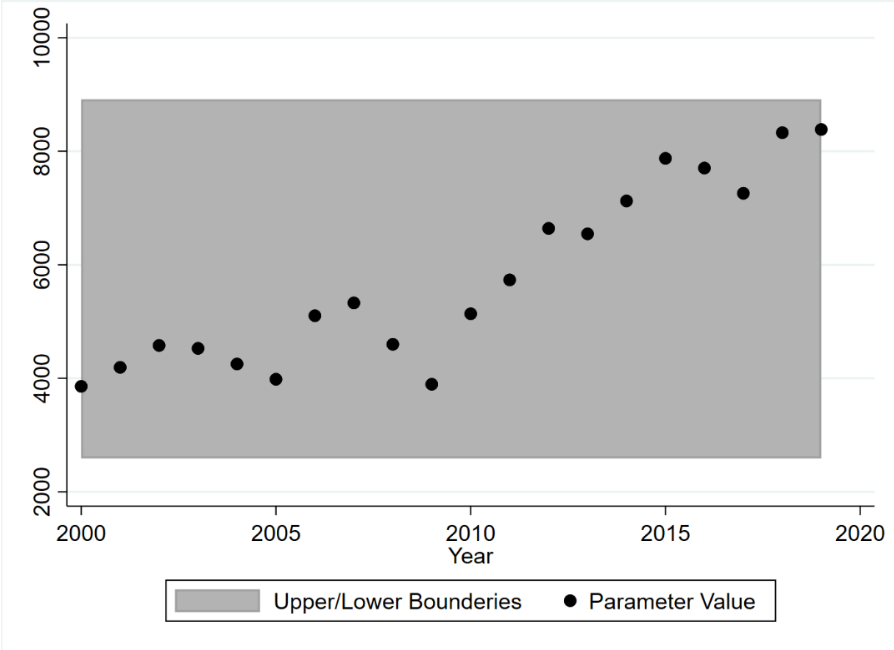

Figure A2.3: Outlier Check in the Non-renewable Contribution per capita Parameter

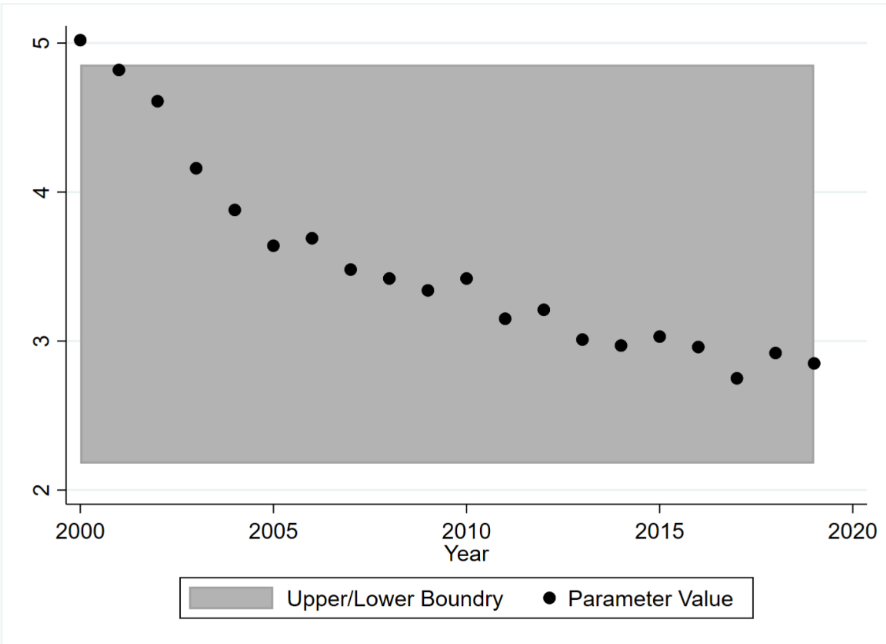

Figure A2.4: Outlier Check in the Energy Intensity Parameter

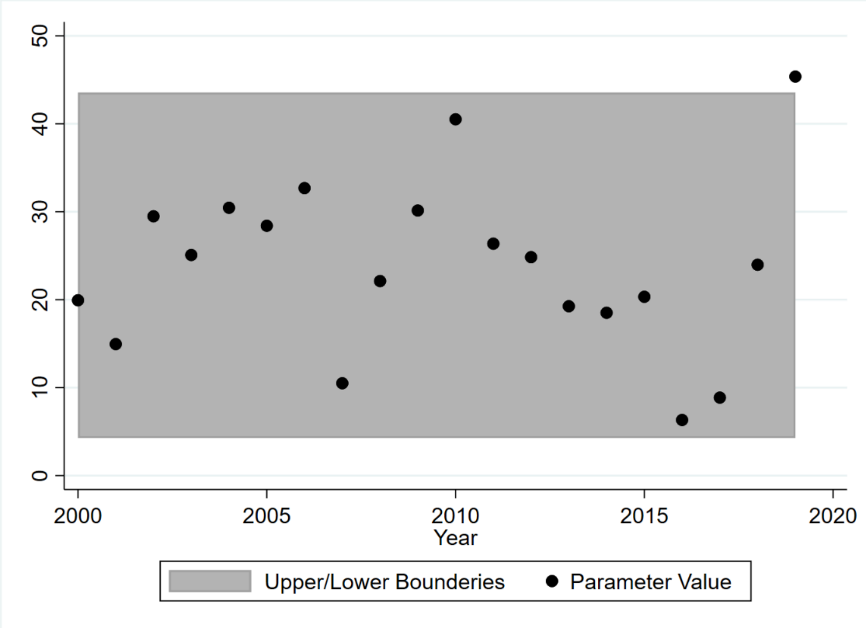

Figure A2.5: Outlier Check in the Exports per capita Parameter

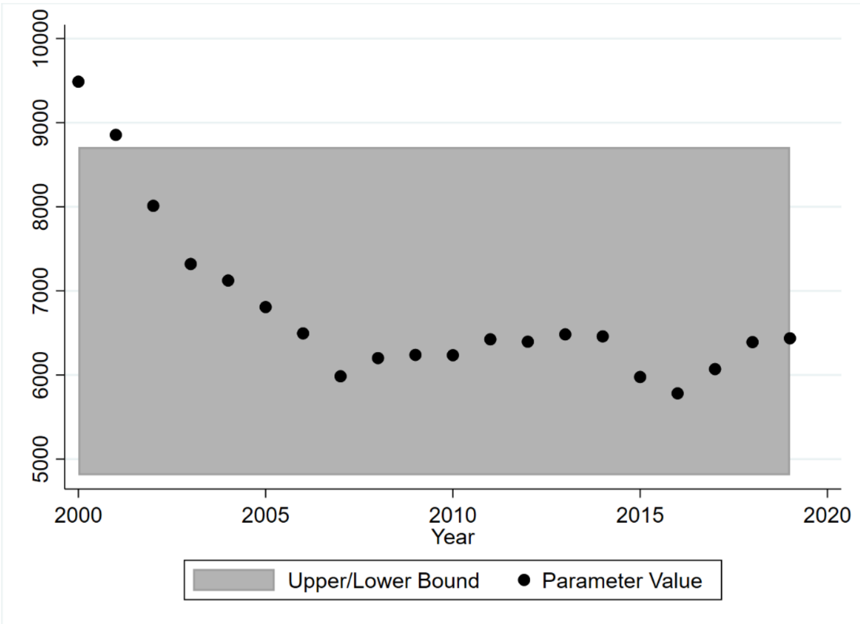

Figure A2.6: Outlier Check in the Renewable Contribution per capita Parameter

No outliers were detected in the data for the Carbon Intensity- and Non-renewable contribution per capita parameters. This is seen in Figures A2.2 respectivly A2.3 above. Further, one outlier was found in the data for the Imports per capita, Energy Intesnity and Exports per capita parameters, seen in Figures A2.1, A2.4 and A2.5.. This while two outliers were detected in the Renewable Contribtuion per capita parameter.

All the detected outlier values are close to bouderies of acceptable values. In other words, all detected outliers are argubly close to being within two standards deviations distance from the mean. In that sense, it is close that the outlier values could be considered to be non-outliers.

This implies that the impact of these values are potentially small. However, to examine this more thourougly, a normalization was done using the highest non-outlier value. This to properly investigate how the outliers affect the output of the normalized data. The values from this normalization is seen in Table A2 on the next page. In this table are also the values of the normalization including the outlier value, to be able to compare their differences.

For the parameters with only one outlier, the values normalized with and without outliers are very similar. The differences is that the outliers gains a value lower than 0 or higher than 1 when the normalization is done with the highest non-outlier value as maximum value. In other words, the outliers of the Import per capita- and Energy Intensity parameters gets a value lower than 0 when the normalization is done on a non-outlier minimum value. This while the outlier gets a value higher than 1 in the Export per capita parameter.

Similarly, the two outliers found in the Non-renewable contribution per capita-parameters also obtains values higher than 1 when normalization is done with a non-outlier value as maximum value. The rest of the values are following a similar pattern, no matter the maximum values. Although the differences in output is not major, it is bigger for the Non-renewable contribution parameter than the rest of the parameter.

As the desired output of the SDG 7 index is a value between 0 and 1, it is not desirable to have parameters with values above or below this range. A solution to this outlier-situation would be to remove the years with outlier values. However, this is not a desierable solution, given that as much time as possible is wanted when constructing the SDG 7 composite index. Given that the differences in normalization output it not affected to a large extent by the presence of the outliers, the decision is made to keep outlying values in the data for generating the SDG 7 composite index.

Table A2: Test for Impact of Outliers, given Normalization Method

Year	Imports per capita	Import per capita without Outlier	Energy Intensity	Energy Intensity without Outlier	Export per capita	Exports per capita without Outlier	Renewable contribution per capita	Renewable contribution per capita without Outlier
2000	0,2079	0,0031	0,0000	-0,0966	0,3485	0,3981	1,0000	1,6617
2001	0,5962	0,4919	0,0881	0,0000	0,2210	0,2524	0,8293	1,3781
2002	0,0000	-0,2584	0,1806	0,1014	0,5931	0,6774	0,6018	1,0000
2003	0,2054	0,0000	0,3789	0,3188	0,4804	0,5487	0,4152	0,6899
2004	0,2790	0,0926	0,5022	0,4541	0,6179	0,7057	0,3621	0,6017
2005	0,3500	0,1820	0,6079	0,5700	0,5655	0,6459	0,2770	0,4603
2006	0,5159	0,3908	0,5859	0,5459	0,6752	0,7711	0,1925	0,3198
2007	0,6797	0,5970	0,6784	0,6473	0,1070	0,1222	0,0549	0,0913
2008	0,8096	0,7604	0,7048	0,6763	0,4045	0,4619	0,1133	0,1883
2009	0,8717	0,8386	0,7401	0,7150	0,6100	0,6966	0,1235	0,2052
2010	0,9417	0,9266	0,7048	0,6763	0,8756	1,0000	0,1226	0,2037
2011	0,9611	0,9510	0,8238	0,8068	0,5134	0,5863	0,1735	0,2883
2012	0,9302	0,9122	0,7974	0,7778	0,4741	0,5414	0,1658	0,2756
2013	1,0000	1,0000	0,8855	0,8744	0,3312	0,3782	0,1893	0,3145
2014	0,9847	0,9808	0,9031	0,8937	0,3122	0,3565	0,1829	0,3040
2015	0,8756	0,8435	0,8767	0,8647	0,3587	0,4097	0,0526	0,0874
2016	0,5532	0,4378	0,9075	0,8986	0,0000	0,0000	0,0000	0,0000
2017	0,8228	0,7770	1,0000	1,0000	0,0651	0,0743	0,0780	0,1297
2018	0,9345	0,9175	0,9251	0,9179	0,4520	0,5162	0,1644	0,2732
2019	0,9438	0,9293	0,9559	0,9517	1,0000	1,1421	0,1768	0,2938

Appendix 3.

Table A3: Original Values (Pre-normalization)

Year	Export per capita	Renewable contribution per capita	Import per capita	Non-renewable contribution	Carbon intensity	Energy intensity
2000	392	9486,857	864	3857,761	0,0218	5,02
2001	302	8854,326	462	4191,863	0,0236	4,82
2002	612	8011,229	1146	4578,421	0,0284	4,61
2003	535	7319,706	940	4526,479	0,0283	4,16
2004	667	7123,111	878	4252,461	0,0268	3,88
2005	639	6807,729	815	3982,652	0,0290	3,64
2006	755	6494,469	629	5102,408	0,0318	3,69
2007	249	5984,846	435	5327,908	0,0340	3,48
2008	538	6201,178	275	4598,82	0,0323	3,42
2009	752	6238,896	198	3894,696	0,0396	3,34
2010	1036	6235,658	106	5137,174	0,0385	3,42
2011	691	6424,163	81	5733,977	0,0369	3,15
2012	667	6395,842	128	6640,577	0,0417	3,21
2013	530	6482,745	27	6545,108	0,0436	3,01
2014	522	6459,196	51	7124,419	0,0393	2,97
2015	587	5976,183	223	7874,466	0,0395	3,03
2016	187	5781,334	745	7703,724	0,0403	2,96
2017	268	6070,544	320	7259,163	0,0422	2,75
2018	740	6390,604	140	8327,313	0,0411	2,92
2019	1430	6436,472	127	8383,617	0,0429	2,85

Table A4: Normalized values - Min-Max Method

	Positive correlation (Equation. 4)		Negative correlation (Equation. 5)			
Year	Export per capita	Renewable contribution per capita	Import per capita	Non-renewable contribution	Carbon intensity	Energy intensity
2000	0,349	1,000	0,208	1,000	1,000	0,000
2001	0,221	0,829	0,596	0,926	0,922	0,088
2002	0,593	0,602	0,000	0,841	0,698	0,181
2003	0,480	0,415	0,205	0,852	0,706	0,379
2004	0,618	0,362	0,279	0,913	0,773	0,502
2005	0,566	0,277	0,350	0,972	0,672	0,608
2006	0,675	0,192	0,516	0,725	0,544	0,586
2007	0,107	0,055	0,680	0,675	0,441	0,678
2008	0,404	0,113	0,810	0,836	0,489	0,705
2009	0,610	0,123	0,872	0,992	0,184	0,740
2010	0,876	0,123	0,942	0,717	0,236	0,705
2011	0,513	0,173	0,961	0,585	0,309	0,824
2012	0,474	0,166	0,930	0,385	0,086	0,797
2013	0,331	0,189	1,000	0,406	0,000	0,885
2014	0,312	0,183	0,985	0,278	0,193	0,903
2015	0,359	0,053	0,876	0,112	0,190	0,877
2016	0,000	0,000	0,553	0,150	0,150	0,907
2017	0,065	0,078	0,823	0,248	0,063	1,000
2018	0,452	0,164	0,934	0,012	0,114	0,925
2019	1,000	0,177	0,944	0,000	0,032	0,956

Appendix 4.

Table A5: Saaty's (1977) Ranking of Importance for an Analytical Hierarchy Process

Ranking (of importance)	Definition	Description
1	Equal Importance	The two parameters contribute equally to more sustainable energy systems.
3	Weak importance of one over the other	One of the parameters matter slightly more than the other for more sustainable energy systems.
5	Essential importance of one over the other	One of the parameters matter strongly more than the other for more sustainable energy systems.
7	Demonstrated importance of one over the other	One of the parameters is strongly favoured and has a demonstrated stronger effect for more sustainable energy systems.
9	Absolute importance of one over the other	One of the parameters is of absolute more importance than the other for more sustainable energy systems.
2, 4, 6, 8	Intermediate values (between two values)	When compromises between the rankings are necessary.

Appendix 5.

Example of generating weights; Energy Security Indicator:

Step 1: Summarize priority scores by columns.

	Import per capita	Export per capita	EDP
Import per capita	1	1/2	2
Export per capita	2	1	3
EDP	1/2	1/3	1
Sum, priority	3,5	1,83	6

Step 2: Divide the priority scores with the summarized priority score, still in columns.

	Import per capita	Export per capita	EDP
Import per capita	1 / 3,5 = 0,286	0,5 / 1,83 = 0,273	2 / 6 = 0,33
Export per capita	2 / 3,5 = 0,571	1 / 1,83 = 0,545	3 / 6 = 0,5
EDP	0,5 / 3,5 = 0,143	0,33 / 1,83 = 0,189	1 / 6 = 0,167

Step 3: a) Summarize rows and b) divide the sums with the number of parameters (i.e. 3). These are the suggested weights.

	Import per capita	Export per capita	EDP	a) Sum, individual weight	b) Suggested Weights
Import per capita	0,286	0,273	0,33	0,892	0,297
Export per capita	0,571	0,545	0,5	1,627	0,539
EDP	0,143	0,189	0,167	0,491	0,164

Step 4: Calculate Consistency Ratio (CR).

a) Multiply original priority matrix with the suggested weights, column-wise.

	Import per capita	Export per capita	EDP
Import per capita	1 × 0,297 = 0,297	0,5 × 0,539 = 0,269	2 × 0,164 = 0,338
Export per capita	2 × 0,297 = 0,594	1 × 0,539 = 0,539	3 × 0,164 = 0,491
EDP	0,5 × 0,297 = 0,489	0,33 × 0,539 = 0,179	1 × 0,164 = 0,164

b) Summarize the rows and divide with the suggested weights.

Row 1: $\frac{0{,}297+0{,}269+0{,}338}{0{,}297} = \frac{0{,}894}{0{,}297} = 3{,}008$

Row 2: $\frac{0,594+0,539+0,491}{0,539} = \frac{1,624}{0,539} = 3,014$

Row 3: $\frac{0,149+0,180+0,163}{0,164} = \frac{0,491}{0,164} = 3,004$

c) Calculate λ_{max} by dividing the sum from the weighted rows by the number of parameters (i.e. 3).

$$\lambda_{max} = \frac{3,008 + 3,014 + 3,004}{3} = \frac{9,028}{3} = 3,009$$

d) Calculate the consistency index (CI) using the following formula: $\frac{\lambda_{max} - n}{n-1} = CI$.

$$\frac{3,009 - 3}{3 - 1} = 0,005$$

e) Calculate the consistency ratio (CR) by diving the CI with the value from a random index (RI), based on the number of parameters (i.e. 3): $\frac{CI}{RI} = CR$.

When $n = 3, RI = 0.91$.

$$CR = \frac{0,005}{0,91} = 0,053$$

f) Examine CR. As CR < 0,10 the suggested weights in Step 3 can be considered consistent.

Appendix 6.

Table A6: Extraction from Dataset

(1) Year	(2) Population	(3) Total Energy from Renewables (TJ)	(4) Total Energy from Non-renewable (TJ)	(5) Renewable contribution per capita	(6) Non-renewable contribution per capita
2000	19 665 502	186 564	75 865	9 487	3 858
2001	20 195 577	178 818	84 657	8 854	4 192
2002	20 758 326	166 300	95 040	8 011	4 578
2003	21 329 514	156 126	96 548	7 320	4 526
2004	21 906 444	156 042	93 156	7 123	4 252
2005	22 496 951	153 153	89 598	6 808	3 983
2006	23 098 586	150 013	117 858	6 494	5 102
2007	23 708 320	141 891	126 316	5 985	5 328
2008	24 326 087	150 850	111 871	6 201	4 599
2009	24 950 762	155 665	97 176	6 239	3 895
2010	25 574 719	159 475	131 382	6 236	5 137
2011	26 205 941	168 351	150 264	6 424	5 734
2012	26 858 762	171 784	178 358	6 396	6 641
2013	27 525 597	178 441	180 158	6 483	6 545
2014	28 196 358	182 126	200 883	6 459	7 124
2015	28 870 939	172 538	227 343	5 976	7 874
2016	29 554 303	170 863	227 678	5 781	7 704
2017	30 222 262	183 466	219 388	6 071	7 259
2018	30 870 641	197 282	257 070	6 391	8 327
2019	31 522 290	202 892	264 271	6 436	8 384
Change over period:	**(+)11 856 788**	**(+)16 329**	**(+)188 406**	**-3050**	**(+)4 526**

Appendix 7.

Table A7: Main Results

	Indicator Scores					SDG 7 Composite Index Scores	
Year	(1) CE	(2) CI	(3) ES	(4) EI	(5) EA	(6)*	(7)**
2000	0,904	1,000	0,278	0,000	0,250	0,662	0,501
2001	0,811	0,922	0,325	0,088	0,257	0,626	0,492
2002	0,693	0,698	0,348	0,181	0,270	0,542	0,458
2003	0,628	0,706	0,348	0,379	0,281	0,543	0,474
2004	0,634	0,773	0,444	0,502	0,297	0,593	0,532
2005	0,627	0,672	0,437	0,608	0,254	0,575	0,534
2006	0,492	0,544	0,546	0,586	0,328	0,513	0,510
2007	0,420	0,441	0,288	0,678	0,344	0,427	0,426
2008	0,508	0,489	0,487	0,705	0,368	0,513	0,522
2009	0,577	0,184	0,626	0,740	0,377	0,496	0,567
2010	0,463	0,236	0,789	0,705	0,401	0,489	0,570
2011	0,429	0,309	0,598	0,824	0,407	0,475	0,537
2012	0,347	0,086	0,569	0,797	0,376	0,378	0,474
2013	0,364	0,000	0,513	0,885	0,452	0,371	0,483
2014	0,312	0,193	0,498	0,903	0,494	0,399	0,484
2015	0,199	0,190	0,489	0,877	0,476	0,348	0,434
2016	0,193	0,150	0,209	0,907	0,506	0,293	0,363
2017	0,261	0,063	0,324	1,000	0,505	0,330	0,428
2018	0,204	0,114	0,565	0,925	0,513	0,353	0,463
2019	0,204	0,032	0,862	0,956	0,530	0,390	0,544

* Index outcome using the weights of Madurai Elavarasan et al. (2022), Table 4, Section 4.4.4..

** Index outcome using the weights suggested by this thesis, Table 5, Section 4.4.4.

Appendix 8.

Table A8: New Weights for Sensitivity Analysis

	Clean Energy	Energy Security	Energy Intensity	Energy Accessibility	Carbon Intensity	CR
Madurai Elvarasan et al.'s (2022) Weights	-	0,293	0,1872	0,108	0,4118	0,0242
	0,501	0,2471	0,0941	0,0941	-	0,0300
	0,4658	-	0,1611	0,096	0,2771	0,0097
	0,4598	0,1803	-	0,0876	0,2723	0,0304
	0,4495	0,1707	0,1202	-	0,4495	0,0245
Weights of this thesis	0,4118	0,2930	0,1872	0,1079	-	0,0242
	0,4063	0,2875	0,208	-	0,0981	0,0429
	0,4351	0,3092	-	0,1501	0,1056	0,0416
	0,4445	-	0,2832	0,1651	0,1072	0,0234
	-	0,4445	0,2832	0,1651	0,1072	0,0234
Equal/No Weights	0,25	0,25	0,25	0,25	-	0,0000
	0,25	0,25	0,25	-	0,25	0,0000
	0,25	0,25	-	0,25	0,25	0,0000
	0,25	-	0,25	0,25	0,25	0,0000
	-	0,25	0,25	0,25	0,25	0,0000

The excluded indicator is marked by the ‘-‘ notation.

Appendix 9.

Table A9: The SDG 7 scores and their difference*

Year	(1)	(2)	(3)	(4) = (2) - (1)	(5) = (3) - (1)
2000	0,427	0,662	0,501	0,235	0,074
2001	0,442	0,626	0,492	0,184	0,050
2002	0,452	0,542	0,458	0,090	0,006
2003	0,506	0,543	0,474	0,037	-0,032
2004	0,534	0,593	0,532	0,059	-0,002
2005	0,553	0,575	0,534	0,021	-0,019
2006	0,543	0,513	0,510	-0,031	-0,033
2007	0,552	0,427	0,426	-0,125	-0,125
2008	0,579	0,513	0,522	-0,066	-0,057
2009	0,562	0,496	0,567	-0,066	0,006
2010	0,555	0,489	0,570	-0,066	0,015
2011	0,581	0,475	0,537	-0,107	-0,045
2012	0,549	0,378	0,474	-0,171	-0,076
2013	0,586	0,371	0,483	-0,215	-0,103
2014	0,606	0,399	0,484	-0,207	-0,123
2015	0,576	0,348	0,434	-0,228	-0,142
2016	0,596	0,293	0,363	-0,303	-0,233
2017	0,619	0,330	0,428	-0,290	-0,191
2018	0,583	0,353	0,463	-0,230	-0,119
2019	0,596	0,390	0,544	-0,207	-0,052

* Explanation of columns

(1) ’Official’ SDG 7 index scores.

(2) SDG 7 Composite index scores using Madurai Elavarasan et al.’s (2022) weights.

(3) SDG 7 Composite index score using the weights suggested by this thesis.

(4) The difference between the SDG 7 composite index scores using Madurai Elavarasan et al.’s (2022) weights and the ‘Official’ SDG 7 index scores.

(5) The difference between the SDG 7 composite index score using the weights suggested by this thesis and the ‘Official’ SDG 7 index scores.

Appendix 10.

Table A10: Uncertainty Test

	Linear Aggregation						Geometric Aggregation					
Year	W1	W2	W3	W4	W5	W6	W1	W2	W3	W4	W5	W6
2000	0,4863	0,5011	0,4476	0,4018	0,4617	0,6664	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
2001	0,4807	0,4922	0,4506	0,4116	0,4522	0,6335	0,3533	0,3716	0,3436	0,2771	0,3585	0,5078
2002	0,4380	0,4576	0,4281	0,4005	0,4220	0,5387	0,3828	0,4029	0,3799	0,3410	0,3756	0,4866
2003	0,4685	0,4739	0,4499	0,4550	0,4315	0,5474	0,4397	0,4498	0,4276	0,4337	0,4036	0,5189
2004	0,5300	0,5318	0,5156	0,5252	0,4759	0,6057	0,5038	0,5146	0,4992	0,5094	0,4490	0,5828
2005	0,5195	0,5344	0,5182	0,5463	0,4613	0,5753	0,4905	0,5140	0,4984	0,5263	0,4266	0,5564
2006	0,4992	0,5100	0,5146	0,5212	0,4593	0,5182	0,4895	0,5034	0,5079	0,5139	0,4470	0,5132
2007	0,4342	0,4263	0,4151	0,4795	0,3991	0,4257	0,4158	0,4075	0,3946	0,4545	0,3860	0,4132
2008	0,5113	0,5222	0,5205	0,5563	0,4753	0,5085	0,5003	0,5134	0,5116	0,5437	0,4650	0,5027
2009	0,5009	0,5671	0,5713	0,5901	0,5030	0,4502	0,4506	0,5376	0,5414	0,5565	0,4734	0,3892
2010	0,5186	0,5704	0,5983	0,5844	0,5115	0,4663	0,4755	0,5383	0,5634	0,5530	0,4830	0,4177
2011	0,5134	0,5366	0,5510	0,5882	0,4880	0,4613	0,4841	0,5132	0,5280	0,5565	0,4698	0,4358
2012	0,4351	0,4735	0,4925	0,5301	0,4289	0,3497	0,3476	0,4178	0,4358	0,4607	0,3846	0,2569
2013	0,4429	0,4828	0,4955	0,5569	0,4527	0,3295	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
2014	0,4800	0,4838	0,4996	0,5665	0,4682	0,3861	0,4219	0,4373	0,4550	0,5020	0,4343	0,3360
2015	0,4460	0,4342	0,4590	0,5229	0,4267	0,3487	0,3779	0,3671	0,3964	0,4365	0,3769	0,2934
2016	0,3931	0,3635	0,3649	0,4799	0,3834	0,2865	0,3083	0,2881	0,2901	0,3694	0,3210	0,2306
2017	0,4303	0,4281	0,4335	0,5450	0,4259	0,3054	0,3057	0,3416	0,3479	0,4191	0,3556	0,2014
2018	0,4641	0,4635	0,4943	0,5537	0,4547	0,3459	0,3620	0,3763	0,4106	0,4454	0,3866	0,2564
2019	0,5166	0,5440	0,6003	0,6157	0,5133	0,3775	0,3091	0,3841	0,4346	0,4420	0,3835	0,1780