Dimensions of Energy Sustainability Measurement

Moses Jeremiah Barasa Kabeyi
mkabeyi@uonbi.ac.ke
Industrial Engineering Department,
Durban University of Technology,
Durban South Africa

Oludolapo Akanni.
oludolapoo@dut.ac.za
Industrial Engineering Department, Durban University of Technology,
Durban South Africa
Correspondence to: Moses Jeremiah Barasa Kabeyi: mkabeyi@uonbi.ac.ke

Abstract

The overall objective of this research is to identify both current and future technologies, strategies, policy, and other measures necessary to transition the electricity and heat energy sector towards reduced greenhouse gas emissions and limit temperature rise to the target 1.5°C rise above the preindustrial level. The greatest sustainability challenge facing humanity today is the greenhouse gas emissions and the global climate change with fossil fuels led by coal, natural gas and oil contributing 61.3% of global electricity generation in the year 2020. The cumulative effect of the Stockholm, Rio, and Johannesburg conferences identified sustainable energy development (SED) as a very important factor in the sustainable global development. This study reviews energy transition strategies and proposes a roadmap for sustainable energy transition for sustainable electricity generation and supply in line with commitments of the Paris Agreement aimed at reducing greenhouse gas emissions and limiting the rise in global average temperature to 1.5°C above the preindustrial level. The sustainable transition strategies typically consist of three major technological changes namely, energy savings on the demand side, generation efficiency at production level and fossil fuel substitution by various renewable energy sources and low carbon nuclear.

For the transition remain technically and economically feasible and beneficial, policy initiatives are necessary to steer the global electricity transition towards a sustainable energy and electricity system. Large-scale renewable energy adoption should include measures to improve efficiency of existing nonrenewable sources which still have an important cost reduction and stabilization role. A resilient grid with advanced energy storage for storage and absorption of variable renewables should also be part of the transition strategies. From this study, it was noted that whereas sustainable development has social, economic, and environmental pillars, energy sustainability is best analysed by five-dimensional approach consisting of environmental, economic, social, technical, and institutional/political sustainability to determine resource sustainability. The energy transition requires new technology for maximum use of the abundant but intermittent renewable sources a sustainable mix with limited nonrenewable sources optimized to minimize cost and environmental impact but maintained quality, stability, and flexibility of an electricity supply system. Technologies needed for the transition are those that use conventional mitigation, negative emissions technologies which capture and sequester carbon emissions and finally technologies which alter the global atmospheric radiative energy budget to stabilize and reduce global average temperature. A sustainable electricity system needs facilitating technology, policy, strategies and infrastructure like smart grids, and models with an appropriate mix of both renewable and low carbon energy sources.

Key Words:
Energy transition; energy and electricity sustainability; sustainable electricity; renewable energy; smart grids; smart energy; 100% renewable energy; Decarbonisation; Electricity system optimisation

Introduction

Energy transition refers to pathways toward the transformation of the global energy sector from fossil-based sources to zero carbon sources. At the center of the energy transition is to reduce energy related greenhouse gases to reduce or limit global climate change. The use of renewable energy resources and application of energy efficiency measures has the potential to reduce carbon emissions by about 90% (IRENA 2022a; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju 2022b). The desired energy transition will be facilitated by smart technologies and smart energy systems, advanced information technology, facilitating policy and legal framework and use of energy market instruments(IRENA 2022b; Moses Jeremiah Barasa Kabeyi & O A Olanrewaju, 2022). Therefore, energy transition represents a significant change in the energy systems which include changes in energy supply, energy processing, energy conversion, delivered, and consumption as well as changes in markets and policies. This transition has important implications as well as effects beyond the affected energy system itself, and leads to transformation of the economy, society, and the environment (IRENA 2022a, 2022b; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju 2022).

There is a global effort to limit the global temperature rise in the 21st century below 2^0C above the pre-industrial levels and to put in measures to limit the rise to 1.5^oC the curtesy of the Paris Agreement reached at COP21 ratified by 192 countries(Moses jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022a; Taliotis et al., 2020). This can be attained by cutting down the greenhouse gas emissions by 45% CO_2 from the 2010 by 2030. Decarbonization of global economies needs a total overhaul and transformation of the whole energy system at generation, transmission, distribution, and end use. Various measure needed include increased use of renewable sources, efficiency measures, electrification of transport, industrial and domestic services, and operations, among others (Gryparis et al. 2020; Taliotis et al. 2020). The global transition of energy systems is extremely important because energy generation and use is the cause for the majority of greenhouse gas (GHG) emissions [2]. An ideal transition should increase the shares of renewable energy (RE) as well as low carbon sources mainly nuclear. The transition is already underway as demonstrated by provision of more than 27% of the global electricity by end of 2019 from renewable sources with 11% coming from new renewable energy technologies, particularly wind turbines and solar photovoltaics (PV). The main driver for increased generation from renewable sources is reducing costs making renewable electricity cost-competitive conventional fossil fuel power plants. On thermal applications, about 10.1% of the global heat applications in 2019 came from sustainable sources. Electrification of transport and other energy applications also promise to provide a leading avenue to emission reductions globally while replacement of fossil fuels with biofuels, hydrogen and biomethane will further reduce the global emissions load(Bogdanov et al. 2021).

The global greenhouse emissions remain high mainly on account of fossil fuel combustion. In the year 2018, the total greenhouse gas emissions were about 55.3 $GtCO_{2e}$ of which 37.5 $GtCO_2$ came from fossil fuels combustion in power generation and other energy applications(United Nations Environmental Program(UNEP), 2019). This makes the energy sector vital in the global effort to tackle climate change as it accounts for about two thirds of global carbon dioxide emissions(Quitzow 2021), yet energy particularly in form of electricity and heat drive the prosperity of the global[1]. For the economy to grow, energy consumption must also increase. For example, from the 1970s, the global gross domestic product (GDP) has grown by about 4.5 times, while primary energy consumption has grown from 155.22 EJ in 1965 to 556.63 EJ in the year 2020 which represents about 3.4 times. Alternative sources of energy should be developed and use because the proven reserves for fossil fuels will soon be depleted. By the end of 2020 the proved reserves for oil will last for 48.8 years. Natural gas will last for 53.5 years while coal is estimated to last for the next 139 years(BP, 2021). These fossil fuels account for 85% of the total primary energy consumption globally. The current era is faced with the challenge of global warming as the most prominent environmental issue thus reduction of carbon emissions is at the center of global environmental policy. It is therefore important to understand the relationship between economic development and energy consumption, and effectively improve energy efficiency for a better relationship and sustainable development(Barasa Kabeyi & Olanrewaju 2022; Jin et al. 2022).. Electricity plays a very important role in modern economies as it provides a rising share of energy generation and consumption in all countries(Solarin et al. 2021). Electricity demand is poised to increase further due to increasing household incomes, and electrification of transport and thermal energy applications as well as continues growth for digital connected devices and air conditioning(International Energy Agency, 2019). Energy is a critical requirement for sustainable development and therefore optimum selection of low carbon and green energy sources remains a key objective for all nations(Bhowmik et al.2020). Electric power plays an important role in human life because all vital activities and operations today need electricity directly or indirectly(Bayram & Ustun, 2017; Beaudin & Zareipour, 2015).

There is need for a transition roadmap to renewable energy sources that may be unique to each country based on local resources and prevailing circumstances (Iddrisu & Bhattacharyya 2015). Energy transition is a reality for all nations because of the targets set in the Paris agreement.

The global community is developing decarbonization plans aimed at reducing greenhouse gas emission in a sustainable manner(Kabeyi & O. A. Olanrewaju, 2020). The process is unique to different countries because the transition is affected by local social and economic conditions. The complexity and comprehensiveness of the energy transition is influenced by the diversity of actors involved in their interests which are often in conflict with one another(Krzywda et al. 2021). Electricity is a very important form of end-use energy, and it is a leading factor for economic growth and development. However, electricity generation is a leading source of greenhouse gas emissions which cause global warming and climate change which threatens sustainable development. This is because most of the global electricity is generated from fossil fuel sources of energy. Electricity accounts for a significant share of the three components that make up total energy production and consumption are electricity, transport, and heating (Ritchie & Roser 2020). The main challenges facing the electricity sector are the ever growing electricity demand, growing need to reduce greenhouse gas emissions and the need realize zero-net carbon emissions in power generation in line with the Paris Agreement which seeks to limit the increase in average global temperature to 1.5^{0}C (Colangelo et al. 2021). This calls for an energy transition from the fossil fuel dominated electricity mix to one dominated by renewable sources of energy and low carbon nuclear as well as clean fuel and conversion technologies(Kabeyi & O. A. Olanrewaju 2020; Moses Jeremiah Barasa Kabeyi & Oludolapo A. Olanrewaju 2021).

The world has so far witnessed three typical energy transitions. The first transition involved replacement of wood with coal as the main energy source. In the second transition, oil replaced coal as the dominant energy resource. In the third transition, there is global commitment to replace fossil fuels with renewable energy. As in 2018, 80% of the global energy was derived from fossil fuel energy resources with 36% being petroleum, 13.2% for coal, and 31% was from natural gas(Lu et al. 2020). Energy transition refers changes undertaken in fundamental processes in charge of evolution of human societies that drive and are driven by technical, economic, and social changes(Smil 2010). It is a new path for economic development and innovation that does not compromise the environmental integrity and sustainability motivated by challenges caused by greenhouse gas emissions, climate change and natural resource depletion(Mostafa 2014). Energy transition consists of processes of structural changes to the subsystems of society which lead to greater sustainability in the society(Kabeyi 2019b).

Therefore energy transitions call for changes in existing policies, technology as well as supply and demand patterns for electricity and other energy resources(Mostafa 2014). The world is said to be undergoing a fourth energy transition today having witnessed three energy transitions in the past. The main objective of this fourth transition is to fight the global climate change through decarbonization of the energy supply and consumption pattens(Mitrova & Melnikov 2019). Therefore a sustainable energy transition system must be driven by the climate change agenda, technology developments and innovation, increased energy efficiency, competitive economies, enhanced energy security, development of affordable energy solutions and measures and modernization of the energy sector from traditional energy systems(Mitrova & Melnikov, 2019; Smil 2010). The International Renewable Energy Agency (IRA) defines energy transition as the pathway in the transformation of the global energy sector from fossil-dominated mix to zero-carbon by the second half of the 21st century(Inglesi-Lotz 2021).

The selection criteria for development sustainable energy transition should consider the environmental, technical, social, institutional, and economic dimensions of sustainability. While choosing or selecting energy sources for electricity generation, the choice of conversion technology and cost involved play a crucial role in modern economies and societies (Bhowmik et al. 2020; Kabeyi & O. A. Olanrewaju 2020). With continuous increase in global population and socio-economic activities leading to increased urbanization, and industrialization around the world, the demand for natural energy resources and more so renewable energy is gradually increasing(Ebrahimi & Rahman, 2019). It is notable that the world's population has grown by 2.5 times since 1950, while energy demand over the same period has grown by 7 times(Şengül et al. 2015). These increasing energy demand is predominantly met by fossil fuel combustion and nuclear power plants (Tunc et al. 2012). With ever increasing energy demand, the related challenges are depletion of fossil fuel reserves, their price volatility , and global climate change which have attracted much attention to renewable energy sources and other low carbon and cheap sources of energy for power generation. As a result, many countries have adopted policies, strategic and operational measures to support the growth of renewable energy sources and other sustainable energy measures in the energy transition (Ebrahimi & Rahman 2019).

Sustainable energy transitions require formulation of effective policies that promote the biomass resources, increased use of renewable and low carbon sources and penalize as well as discourage the use of fossil fuels and unsustainable natural resource use. Directing agricultural resources toward food production(Andress et al. 2011). Renewable energy like solar, wind power, or hydropower can be used as viable options for generating electricity. Solar power plants, for example, could be constructed in countries with vast expanses of desert land. With developing countries like China having huge coal reserves and high electricity demand, coal fired power plants will continue to dominate electricity generation in these countries and options like clean coal technologies and carbon capture and sequestration are critical options. Production of hydrogen from coal is another strategy. For countries with high electricity demand, nuclear power generation is an option for reducing GHG emissions although with a danger of proliferation for politically unstable governments with weapons agenda. Large scale penetration of renewable energy requires development of advanced batteries, high efficiency conversion technologies, and stable and resilient grids to absorb variable renewable energy sources. Electrification of transport with most electricity coming from low carbon and green sources is another strategy for the sustainable energy transition. (Andress et al. 2011).

There are various strategies, measures and technologies that can be used to improve sustainability. They include energy efficiency, increasing the contribution of renewable energy in electricity generation, use of Carbon Capture and Storage (CCS) in fossil and biomass power plants, use of low carbon nuclear power, use of hydrogen in the transportation sector and reductions in the demand for energy and electrification as well as use of biofuels in transport services. The main challenges facing various options and technologies include lack of acceptance and behavioral changes as well as cost limitations and availability of cheap fossil fuels (Hildingsson & Johansson 2016).

This study examined sustainability in energy and particularly electricity generation systems and the challenges and opportunities of sustainability. The overall objective was to lay a framework for a sustainable transition to a green and low carbon electricity grid system as a contribution to the global effort to fight the climate change and greenhouse gas emissions. Various pathways to sustainable electricity generation are examined and proposals made on a feasible roadmap to a sustainable energy transition, particularly grid electricity generation, transmission, distribution, and consumption. The transition acknowledges the significance of nonrenewable sources and their main challenges of intermittence and variability as the global community seeks to transition to green energy sources. Using a critical discourse analysis, the study attempts to develop a roadmap that can be adopted by nations based on their local conditions to sustainably transition their electricity production and supply. Of particular concern is how the available energy sources can be used to realize the Paris targets without compromising the socio-economic and environmental set up and hence achieve sustainable energy transition

1.1. Problem Statement

There is growing urgency for large, rapid and sustained greenhouse gas emissions reductions to avoid the danger of global warming. These calls for emission reduction in all sectors especially heavy polluters like transport, agriculture and power generation. With power generation accounting for over 40% of total emissions, availability of low carbon substitutes and capacity of electricity as an energy carrier, emission reduction will have a significant global impact (Elliston et al. 2014). Whereas the costs Solar PV and wind have been reducing, they are highly variable and unpredictable which is a real challenge for a secure and reliable electric power system operation and maintenance as there deployment needs highly dispatchable generation capacity on standby which is conventionally supplied by coal, gas and diesel affected by interruptions from plant failures, and to fuel supply interruptions, droughts, and price fluctuations (Monyei et al. 2019). Electricity systems are witnessing a profound transformation, with a greater role for smarter grids going hand in hand with increased solar and wind deployment. Electricity grids i.e. transmission and distribution systems provide the bedrock of today's and tomorrow's power systems, enabling electricity to flow and all sources of flexibility to contribute to electricity security. Grids expansion must accelerate over the next decade to connect all new sources of electricity, including renewables, extending grids by 16 million kilometres, 80% more than over the past decade (International Energy Agency, 2020). This calls for optimum deployment of electricity power plants and infrastructure.

The emission of greenhouse gases (GHGs) and their implications to climate change have sparked a global interest in understanding the relative contribution of the electrical generation industry. According to the Intergovernmental Panel on Climate Change (IPCC), the world emits approximately 27 gigatonnes of CO_2e from multiple sources, with electrical production emitting 10 gigatonnes, or approximately 37% of global emissions. In addition, electricity demand is expected to increase by 43% over the next 20 years. This substantial increase will require the construction of many new power generating facilities and offers the opportunity to construct these new facilities in a way to limit GHG emissions (Kabeyi & Oludolapo 2020b).

The global community agreed during the Paris conference of 2015 to keep the global temperature at a maximum of 2ºC above the preindustrial level ((Xia et al. 2019). The emission of greenhouse gases with carbon dioxide (CO_2) being the most dominant are directly responsible for global warming (International Energy Agency 2018). Carbon dioxide from fossil based combustion mainly in power plants is a significant contributor of the greenhouse gas emissions accounting for about 80% growth of emissions (Intergovernmental Panel on Climate Change, 2014; Wang et al. 2019). This calls for maximum integration of renewable and low carbon sources which comes with significant challenges to the electricity grid. The stability of the grid is realized by line stability, voltage stability, and adequate control of reactive and active power with the objective of increasing and maximizing absorption from renewable energy sources. However large scale integration of renewables can lead to loss of synchronism, collapse of voltage, load shedding and significant deviation of system voltage and frequency which then leads to flicker, harmonics, high transmission and distribution losses, overloads and power oscillations which is highly undesirable and unsustainable (Sreedharan et al. 2015). Simultaneous reactive power management of transmission and distribution grid can maximize the renewable penetration at all layers of the grid.

The climate has been changing and consequences are being felt globally. Many developing countries including south Africa are facing the three challenges of grid electricity namely cost, quality & reliability and environmental impact. The Paris Agreement set targets for all countries to reduce carbon emissions (Intergovernmental Panel on Climate Change, 2014; Intergovernmental Panel on Climate Change 2001). Most of carbon emissions come from power plants of which 60% of global electricity comes from fossil fuel-based sources. Renewable sources like solar and wind which are significant face the challenge of intermittence and hence are unpredictable and unreliable. We must however use them as well as other renewables and low carbon sources to mitigate against carbon emissions and global warming while not compromising the cost, security and quality of grid electricity(Akom et al. 2021).

The global emissions reduced by 5.8% in 2020, which is about 2 Gt CO_2 which represents the greatest ever decline and almost five times greater than the decline realized in 2009 caused by global financial crisis. Even with decline in energy demand in the 2020 due to Corona pandemic, the global energy greenhouse gas emissions remained about 31.5 Gt, with average annual atmospheric CO_2 concentration reaching 412.5 parts per million (ppm) in 2020 – representing about 50% above the preindustrial industrial revolution level (International Energy Agency, 2021a). Most of the electricity generated globally is comes from fossil fuel-based power plants, industry, and transport. These energy resources are generally expensive, scarce, exhaustible, polluting, and insecure since not all nations are endowed with the primary resources hence a source of energy insecurity, while the combustion of fossil fuels produces greenhouse gases like carbon dioxide (CO_2), Sulphur dioxide (SO_2), Nitrous oxides (NOx), which are the main causes of the global warming that is threatening the very existence of humanity and mother nature. This concern is the main motivation behind sustainable energy transition by increased use of renewable and low carbon clean energy sources especially solar, wind, biomass, hydro and nuclear. These renewable and low carbon sources improve and widen power supply, enhance long term access and utility in energy production, decrease dependence on fossil fuel, and reduce greenhouse gas emissions(Nguyen et al. 2020; Rathor & Saxena 2020).

Natural increases in CO_2 concentrations have historically been warming the earth during ice age cycles for millions of years. These warm episodes are said to have started with slight increase in solar radiations reaching the earth due to a slight wobble in earth's axis and path of rotation around the Sun that caused some notable warming. This phenomenon caused the warming of oceans leading to an increase in carbon dioxide (CO_2) emissions from the oceans. However, CO_2 concentration never exceeded 300 ppm during these periods that took place about a million years ago. Before the industrial revolution that started in of mid-1700s, the global average amount of carbon dioxide was about 280 ppm (Lindsey 2020). Figure 1 shows the historical growth of CO_2 emissions and concentration between 1750 and 2020.

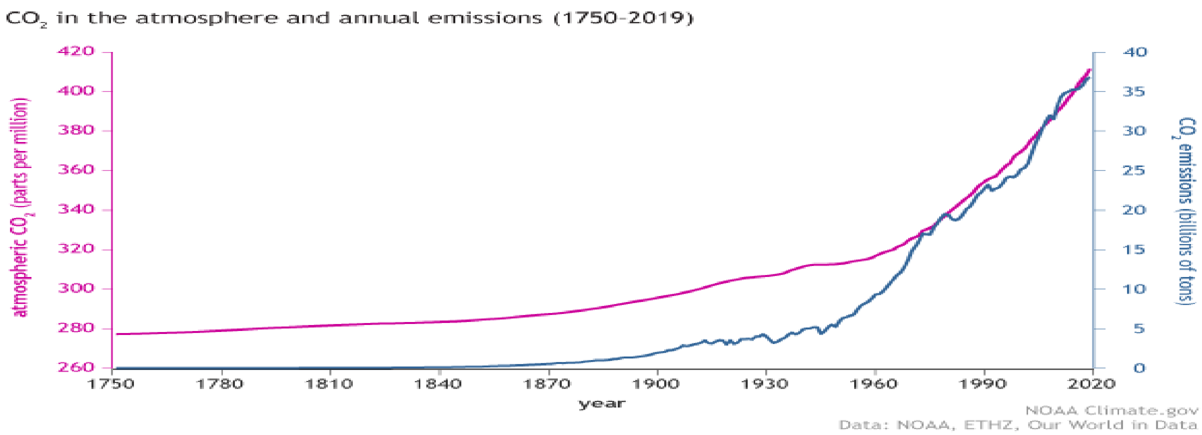

Figure 1. Concentration of Carbon Dioxide Emissions between the year 1750 and 2020 (Lidsey, 2020; Lindsey, 2019)

Figure 1 shows that the global CO_2 emissions remained constant between 1750 and about 1840 where they started to increase rapidly. The atmospheric concentration increased slightly between 1750 and 1960 before the rate increased between 1960 and the year 2020 mainly due to higher level of industrial activities and increasing use of fossil fuels. Therefore, it is the entry of fossil fuels in the energy mix that triggered rapid increase in CO_2 emissions as the level of industrialization developed.

Fossil fuels continue to dominate the current energy systems and therefore significantly contribute to the global carbon dioxide (CO_2) and other greenhouse gases emissions to the atmosphere. To realize the global climate targets and avoid destructive climate change, there is need for a global transition in electricity generation, transmission, and distribution and as well as its consumption. Humanity must strike a balance between developmental needs and the environmental conservation and protection. The main challenges facing renewable energy sources is resource availability, resource access, resource location, security of supply, sustainability, and affordability (Samaras et al., 2019). The growing demand for electricity has led to increased demand and consumption of fossil fuels and growing level of economic activities have contributed to growth of the greenhouse gas emissions and consequently, global warming(Wang, 2019). The transition challenges are further compounded by the fact that efforts to promote more sustainable, more resilient, and equitable energy disrupts economic, political, and institutional relationships. As a result, issues of power and politics are now central themes in sustainability transition in energy sectors(Lenhart & Fox 2021).

1.2. Rationale of the study

The Paris Agreement of the 21st UNFCCC Conference of Parties (COP21) of 2015 seeks to limit average global temperature increase below 2 °C above pre-industrial levels look for measures to limit the average temperature rise to 1.5 °C the pre-industrial temperature. This calls for drastic measures to reduce anthropogenic emissions and removals by sinks of greenhouse gases by second half of 21^{st} century(Lawrence et al.2018). Studies have shown that the climate is changing mostly because of the anthropogenic activities. The report by Intergovernmental Panel on Climate Change (IPCC) for 2021 indicates that several climate changes are already irreversible but adds that we still have hope for the future if action is taken. To mitigate further changes (Inglesi-Lotz 2021). The climate is very important to man and other living organisms on the planet, yet there is overwhelming evidence that the world is facing changing climatic conditions due to the greenhouse effect as demonstrated by the increase in average global temperature, high incidents of climate related issues like drought, storms and desertification (Wallington et al. 2004). The global anthropogenic activities have led to about 1^{o}C rise in average global temperature above prehistoric level and is further projected to reach 1.5^{o}C between the year 2030 and 2052 if current greenhouse gas emission rates are maintained(Fawzy et al. 2020).

Electricity generation accounts for about 26% of total greenhouse gas emissions making it an important target for emissions control in the war against climate change(Kabeyi & Oludolapo 2020d). The Intergovernmental Panel on Climate Change (IPCC) sought to stabilize the atmospheric air carbon concentration with a target to limit concentration to 350 parts per million (ppm) for CO_2 while maintaining temperature rise of 2^{o}C above the preindustrial level, a target that was ratified by many nations globally. This calls for limitation in the consumption of fossil fuels particularly in electricity generation and transport industries through substitution with renewable energy sources and electrification of transport among other measures. This calls for massive expansion in power generation capacity using renewable energy and low carbon energy sources(Burger et al. 2012). The future of humanity as defined by the sustainable development goals in the face of climate change has made sustainability the concern for all major systems including energy or electricity generation, supply and consumption systems(Vine 2019). There is need for a shift from current dependence on fossil fuels for power generation, transport, and thermal applications(Burger et al., 2012).

The global greenhouse gas emissions can be presented based on economic activities that lead to their production and emission. Greenhouse gases are mainly released by electricity and heat generation in the energy and related sectors, manufacturing activities, industrial operations, transportation, agriculture and forestry as well as the building industry(Marcus 1992). The sources of greenhouse gases can be classified into five economic sectors. These sectors are energy, industry, transport, buildings and AFOLU i.e., agriculture, forestry, and other land uses. (Lamb et al., 2021). In figure 4 below, the greenhouse gas emissions by sector are presented for the years 1990 to 2018 for the entire world and across 10 ten global regions, namely Asia pacific, Africa, East Asia, Eurasia, Europe, Latin America, Middle east, North America, South Asia, and Southeast Asia.

From figure 2, it is noted that the energy sector inn form of electricity and heat production is the largest contributor of greenhouse gases with about 34%, industry at 24% followed by agriculture, forestry and other land activities accounting for 21%, transportation with 14% , while buildings contributed about 6% while the building sector is least with 6% in 2018(Lamb et al. 2021). Figure 2 further demonstrates that for the African region, most emissions

The greenhouse gas emissions (GHG) for 2018 were about 11% (5.8 $GtCO_2eq$) higher than GHG emission levels in 2010 (51.8 $GtCO_2eq$). The energy sector accounted for close to 1/3rd of the increase in GHG emissions between 2010 and 2018 of about 1.9 $GtCO_2eq$, followed by industrial sector with 1.8 $GtCO_2eq$ which was about 30% of the increase, then the transport accounted for 1.2 $GtCO_2eq$ or 20% of the increase. Emissions that came from AFOLU increased by about 0.72 $GtCO_2eq$ equivalent to 12% increase while the buildings sector recorded the lowest increase in emissions with about 0.22 $GtCO_2eq$, or 4%(Lamb et al. 2021).

A sustainable energy transition should address the energy sources, energy conversion, transmission, and consumption especially the leading sectors in energy consumptions like heat and power production, transport related activities including fuel use and conversion. These measures include a shift from fossil fuel sources to renewable and low carbon sources, efficient conversion technologies, electrification of transport with most electricity coming from renewable resources, energy conservation measures and elimination of unnecessary energy demand and consumption.

Energy is far much more than just the technical infrastructure. It is through the energy transition that we realize emergence of innovative business models and organization that drives the establishment of new practices and procedures, and new ways of life, reassign responsibilities, reorganize governance, and redistributes power structure. It is for these reasons that the sustainable energy transition calls for consideration of the social, technical, economic, political, and institutional dimensions of sustainability in addressing challenges of the energy sector in order to sustainably shift to a low-carbon economy and electricity systems which is the main focus of this research(Quitzow, 2021).

Methodology and Novelity of the Study

In this study, low-carbon energy transitions options and strategies are considered governed and proposed in line with broader sustainability goals and requirements as specified by the dimensions of sustainability. The study sought to identify conflicts and synergies between low-carbon strategies and the attainment of both short term and longer-term environmental, economic, technical, social, and institutional objectives. The research framework is organized across the five dimensions of sustainable energy and specifically electricity development which are environmental, economic dimensions, social aspects, technical dimensions, and institutional, political dimensions. The study adopted secondary method of data collection and analysis from recent primary and secondary data found in original research findings and reports from credible peer reviewed sources. This would facilitate the voice of the common people, professional, experts and authorities as well as governments for a cleaner global future. For this research, the term primary data refers to the data originated and carried out and presented as peer reviewed academic and professional papers and reports through personal interviews with the expert team or analysis based on primary data and presented as original reports or peer reviewed journal article. Therefore, this study is a review of the energy sustainable transitions globally. Published literature in the form of technical reports, peer reviewed journals and conference papers were reviewed by the authors. The study is a survey using credible literature from peer reviewed journals papers and energy data from various authorities globally.

Most studies on sustainable energy transition are narrow in scope as they tend to concentrate on the environmental dimension of sustainability. Researchers that look at sustainability more wholistically also tend to concentrate on the three pillars of sustainability, namely economic, environmental, and social dimensions of sustainability(Kabeyi 2019a, 2019e; Krzywda et al. 2021). Past reviews also concentrate on energy sustainability in general. However, in this study, the focus is electricity as a secondary form of energy derived from primary sources of energy like wind, solar, hydro, nuclear, coal and gas through indirect conversion through a generator or direct conversion as in fuel cells and solar photovoltaics.

In most studies undertaken on energy transitions, the focus has been on energy technologies and sources with main objective being minimizing emissions. Others have gone further to address variability and intermittence and to rank sources in order of potential within the framework of the three pillars 0f sustainability. This study is unique as it looks at technical and institutional dimensions in addition to the economic, social, and environmental and hence the role of energy storage and electrification of transport which induces additional variability to demand side. The study also brings into focus the role of the smart grid in managing the dynamic nature of electricity demand and supply in decentralized generation and with the intermittence and variability of wind and solar. The study therefore recognizes that social foundations and human behaviors have a significant role to play in the future sustainability of the energy sector (Inglesi-Lotz 2021). Therefore, the study pays attention and extensively analyses to energy and electricity models and modelling tools that holistically considers sustainability in the energy sector and electricity systems.

Global Electricity Generation

The ever-growing electricity demand is the main reason for growth in global CO_2 emissions from electricity which have now reached a record high. The commercial availability of low emissions generation technologies and energy sources has placed electricity at the center of the global effort to combat climate change and pollution. Decarbonization of electricity has a significant potential to provide a platform for CO_2 emissions reduction by means of increased use of electricity-based fuels such as hydrogen and biofuels. Renewable energy sources and efficiency in resource use and generation has a special role to play in increasing access to electricity globally(International Energy Agency 2019).

The shift and growth in electricity demand adopts two distinct global routes or paths. For most developed countries, demand growth is linked to increasing digitalization and electrification which is largely offset by energy efficiency measures and improvements in process energy efficiency. For the developing countries like China and India, the reasons for growing electricity demand are the growing incomes and better quality of life, industrialization, and growing services sector. It is also worth noting that the developed countries account for about 90% of global electricity demand growth, and the trend may remain so until the year 2040(International Energy Agency 2019).

Today, Industry and building sectors are the main users of electricity accounting for over 90% of global electricity demand. Moving forward, the main drivers of electricity demand growth are motors in industry which may account for over 30% of the total growth to 2040. It is projected that industrial and domestic space cooling will account for 17% while large electrical appliances are projected to account for 10% growth while electric vehicles are projected to account for 10% growth in electricity demand. Further growth in electricity demand of about 2% is projected to come from provision of electricity access to 530 million first time users of electricity. The Sustainable Development Scenario, projects that electric vehicles will become a leading source of electricity demand moving to the future towards the year 2040(International Energy Agency 2019).

The global energy demand and supply has been growing with supply increase of about 60% between 1990 and 2016 when supply hit 568 EJ. The international bunkers was 16.3 EJ in 2016 accounting for 3% of global total energy supply and was marked by a double growth since 1990, an indication of growing activity and hence energy consumption internationally(United Nations(UN), 2019). The global electricity generation more than doubled between 1990 and 2016, to reach about 25,000 TWhrs. Between 1990 and 2016, the largest absolute growth in terms of energy sources came from coal with about 5,300 TWh representing +116% growth. Natural gas supply reached 3,500 TWh representing a growth of +213%.

Renewable sources of energy represented by mainly solar, wind grew by +2,224% or 1,370 TWh over the same period. This was the fastest growth recorded for renewable sources of energy. However, over 75% of electricity in 2016 came from non-renewable sources, mainly from thermal energy accounting for 65% or 16,186 TWh and nuclear 10% or 2,608 TWh. On the positive note, between 2000 and 2016, 50% of new electricity generating capacity came from renewable energy sources(United Nations(UN), 2019; Wanga et al., 2020). Figure 5 below shows the changes in total energy supply between 1971 and 2019.

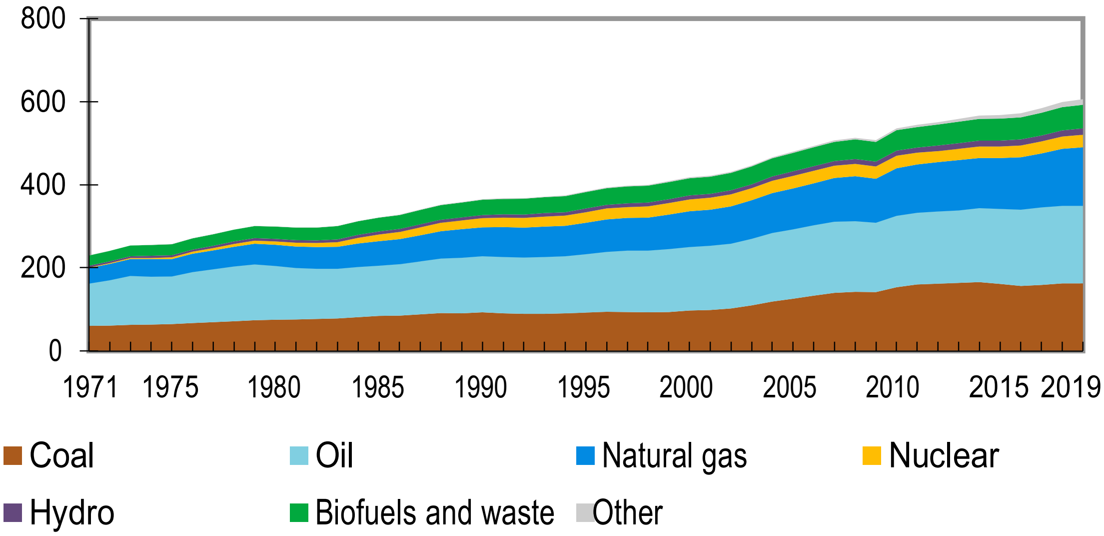

Figure 5. World Total Energy Supply between 1971 and 2019 (International Energy Agency, 2021b; United Nations, 2019a)

From figure 5 above, it is noted that between 1971 and 2019, the proportionate composition of primary energy mix has been changing. The total primary energy consumption increased from 254 EJ in 1973 to 606 EJ in 2019. Biofuels and wastes reduced from 10.5% in 1973 to 9.3% in 2019.Coal consumption increased from 24.7% of total primary energy consumption to 26.8% in 2019. Oil reduced from 46.2% in 1973 to 30.9% in 2019. Natural gas increased from 16.2% of consumption in 1973 to 23.1%. Nuclear increased from 0.9% to 5% while hydro increased from 1.8 to 2.5% of total primary energy consumption in 2019(International Energy Agency, 2021b).

Fossil fuels generated 61% of global in the year 2020 while combined nuclear, wind and solar accounted for 35% of global electricity generation in the year. Solar energy also surpassed oil in global electricity generation 2020 where solar accounted for 3.2% compared to oil that contributed 2.8% of global electricity generation for the year 2020.(World Energy Data 2021). Figure 6 below shows global electricity generation from different sources for the year 2020

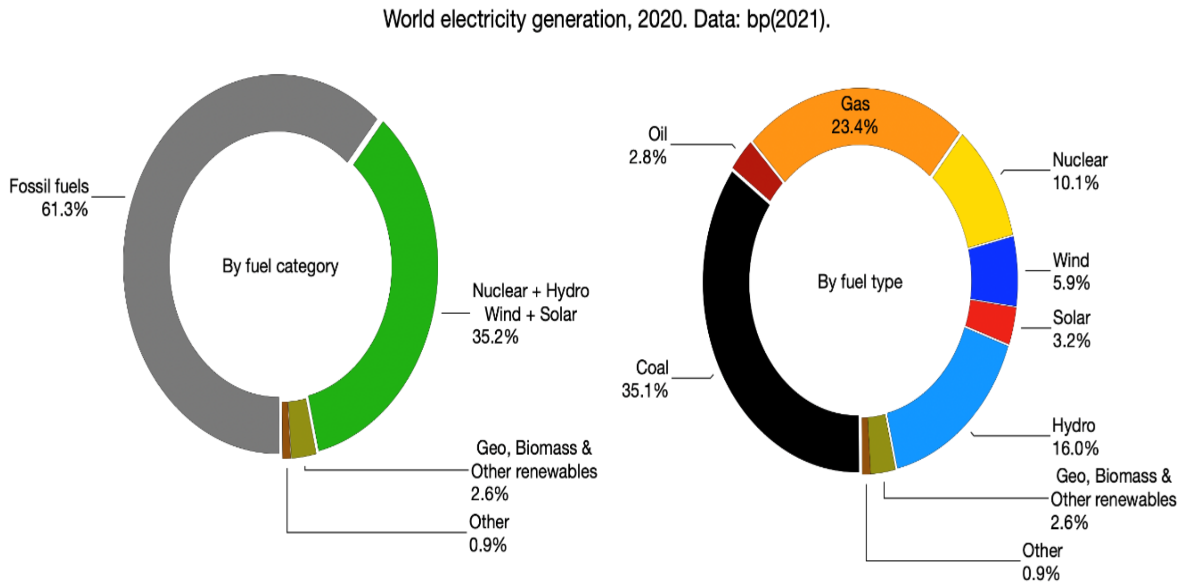

Figure 6. World electricity generation by source for 2020(BP, 2021)

From figure 6, it is noted that for the year 2020, fossil fuels contributed 61.3% of global electricity production, 35.2% was on account of combination of nuclear, hydro, and solar, other renewable s accounted for 2.6% while other sources accounted for 0.9%. Coal contributed 35.1% of global electricity while gas accounted for 23.4% of global electricity.

Sustainable Energy Development

The road to a sustainable energy future has twin challenges of energy access and mitigation of global warming by control of greenhouse gas emissions(Kaygusuz 2012). Energy is at the center of several Sustainable Development Goals. They include expansion of electricity access, improving clean cooking fuels, curbing pollution, and reducing wasteful energy subsidies. Goal number 7 also referred to as SDG 7 – aims to ensure access to reliable, affordable and modern energy for all by the end of the next decade(Birol 2018). The global adoption of energy specific sustainable development goals was an important milestone towards a more sustainable and equitable society. Although energy must be at the heart of efforts to lead the world to a more sustainable pathway., the current and planned policies fall well short of realizing the critical energy-related sustainable development targets. On the positive note, there is tremendous progress in delivering universal electricity access (SDG 7.1.1) for Asia and parts of sub-Saharan Africa(Birol, 2018). As in the year 2012, about 1.4 billion people globally had no access to electricity of which 85% are based in rural areas. It is projected that by the year 20130, about 2.8 billion people globally will be relying on traditional forms of energy mainly biomass, which is an increase from 2.7 billion people in the year 2012(Kaygusuz, 2012). where the number of people without access to electricity declined to 1.1 billion in 2016, from about 1.7 billion in the year 2000. However, it is projected that more than 670 million people will still have no access to electricity in 2030. Therefore a lot more remains to be done in terms of electricity access(Birol 2018).

Lack of access to affordable electricity and reliance on the inefficient and unsustainable traditional energy like fuelwood, charcoal, agricultural waste, and animal dung) are a clear manifestation as well as an indicator of poverty. Modern energy sources and electricity play a an important role in socio-economic development (Kaygusuz 2012; Tracey & Anne, 2008). Reliable electricity and light lengthen the day activities hence provide extra hours for economic activities. Positive contribution of electricity includes saving women and children from exposure to poisonous smoke and long hours of looking for firewood. Hospitals can better sterilise instruments and store medicines in refrigerators. Electricity improves manufacturing and service enterprises by extending the quality and range of their products hence creating more jobs and higher wage(Kaygusuz 2012)

Sustainable Development

There is need to eliminate energy poverty to achieve the *Millennium Development Goals but in* a way that takes the world away from dependence on the fossil fuels to avoid global warming by moving rapidly towards a green economy

(Vezzoli et al., 2018)'. The three interlinked objectives that must be achieved by the year 2030 to realise sustainable energy for all are ensuring universal access to modern energy services, double the share of renewable energy in the global energy mix and double the rate of energy efficiency improvement(Kaygusuz 2012; Vezzoli et al. 2018).

Philosophers, economists and scientists introduced the closely related concepts of sustainable development and sustainability in the 18th, 19th and early 20th centuries (Seghezzo 2009). Sustainable development can further be defined socio-economic growth that delivers the traditional positive progress and targets in an ecologically acceptable manner and with due regard of the future generations' welfare and rights to the same(Kabeyi & O. A. Olanrewaju, 2020; Kabeyi & Oludolapo, 2021). Sustainable is defined as sustained growth, or sustained change or can also be defined simply as development that is successful (Lélé 1991). Sustainability is necessary in energy and other resources exploitation so as man exploits resources to meet his ever-growing energy demand, he does not compromise the ability of future generations to meet their own energy needs and a stable environment (Broman & Robèrt 2017; Kabeyi & O. A. Olanrewaju, 2020). Because of these requirement and expectations, society must strike a balance between economic growth and the social wellbeing of the society as a whole, now and in future to realize sustainability, which is a technical, political and economic challenge(Dyllick & Hockerts 2002). Therefore, the concepts of sustainable development and sustainability has the objective of achieving economic advancement and progress while at the same time conserve the value and integrity of the environment. This calls for a tradeoff between environmental sustainability goals and economic development objectives and targets(Emas 2015).

The publication of Carson's book called "Silent Spring" in 1962 was used as the starting point of the global concern over proper use of natural resources. This can be demonstrated by what emerged 10 years later in 1972 as the 'Club of Rome' that styled itself as an independent analyst and think tank who later published a book called "The Limits to Growth" (Akella et al., 2009; Intergovernmental Panel on Climate Change(IPCC), 2007; Jacobs et al. 1987). In this book, the authors observed that if the global economy and population grew unchecked, the planet earth's natural resources would approach depletion at a point in future. These narrative led to the formation of the UN 'World Commission on Development and Environment', also called the Brundtland Commission, named after its chair, Gro Harlem Brundtland, who was a former Norwegian Prime Minister (Seghezzo 2009; University of Alberta, 2015). The "Brundtland Commission" released its final report that was entitled, "Our Common Future" four years later that defined sustainable development. The report defined sustainable development as a positive change that meets the needs of the present generation without compromising the ability of future generations to meet their own needs in future (University of Alberta, 2015; World Commission on Environment and Development (WCED), 1987).

Therefore the concept of sustainable development is more concerned with whether what is acceptable today and is acceptable or not acceptable to the next generation (Jonathan, 2001). Today, the strategies for sustainable development aim at promoting harmony and wellbeing among human beings and between humanity and Mother nature. Obviously, energy especially in the form of electricity has a central role in any effort to achieve sustainable development. From the use of wastes by industry to generate power and stabilize the grid, and conversion of polluting and eye soring slaughterhouse waste to clean electricity and create jobs keeping humanity clean and healthy fee of diseases, poverty, and physical harm(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2021a; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju 2021a, 2021b; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju 2021b).

Sustainable development and the concept of sustainability calls for integration of economic benefits, social considerations and progress with environmental protection and considerations for maximum positive outcome (Mohamad & Anuge 2016). The United Nations General Assembly in 2015 adopted the 2030 Agenda for sustainable development which as a framework of 17 sustainable development goals (SDGs). This agenda calls for sustainable development which recognizes need to reduce poverty and guarantee equity and integrity of the entire global human community. These 2030 agenda calls for member countries to protect the planet earth from further degradation by taking sustainability measures which include sustainable resource production and consumption, and sustainable management and conservation of the earth's natural resources and prevent climate change (Kabeyi & Oludolapo, 2020d; United States Department of Energy 2015).

There is inherent interdependence between environmental stability and the economy which then lays a strong foundation for sustainable development (Emas 2015). There is however need for public policy that promotes investment in economic and industrial activities that seek to protect the natural environment, promote human and social capital, and prevent the damage caused by pollution, social clashes, resource waste and greenhouse gas emissions which are both indicators and effects of unsustainable practices(United States Department of Energy, 2015). Fortunately, policies that seek to protect the environment and mother nature also promote innovation and profitability by organizations, and this should encourage enforcement, either voluntarily or by legislations. Promotion of innovation and strict environmental regulations can enhance competitiveness and hence economic performance and progress. The link between the environmental integrity and development provides a strong rationale for environmental protection(Kabeyi & O. A. Olanrewaju, 2020; Liu, 2014).

The use of polluter pay principle in environmental protection requires authorities to impose penalties upon those who pollute the environment and hence make them bear the cost of their impact instead of leaving it with the environment or others. There is need to integrate economic, environmental, and social objects across sectors, territories, and even generations if sustainable development can be achieved. This implies that energy policy should be an integral part of the entire national and international agenda and should be therefore be integrated in other policies touching on the economy, society and the environment(Emas 2015). Sustainable energy development should also be taken as a continuous process integrating all aspects of national, local and international development agendas (Mohamad & Anuge 2016). Therefore, sustainable energy development can only be realized through integration of energy objectives, development goals and environmental protection to avoid conflict by creating a critical synergy.

Relationship Between Sustainable Development and Energy

Energy is currently recognized as one of the most important factors that influence the rate of progress as well as sustainable development of all nations(Kolagar et al. 2020). To meet the ever-growing energy demand especially electricity, increase access to electricity for the billions of people with no access to electricity and high-quality low carbon fuels, as well as to reduce greenhouse gas emissions requires a radical shift from the fossil-fuel focused energy systems. There is need for a new energy paradigm to encourage the transformation of the predominantly fossil fuel-based energy systems. Sustainability is an important paradigm in the global energy transition where all dimensions of sustainability are addressed any policy formulation and implementation, planning, operation and dispatch of the energy resources in both generation and consumption(Davidsdottir 2012). For a longtime, energy did not seriously factor in sustainable development. However, sustainable development and sustainability issues now play a central role in energy and electricity by anchoring the evolution of the sustainable development paradigm(Iddrisu & Bhattacharyya, 2015; M. J. B. Kabeyi & A. O. Olanrewaju, 2021).

Specific energy projects influence the economic, social, and environmental dimensions of the sustainability country or region. The triangular approach to the three dimensions of sustainable development consisting of economic, social, and environmental is used to assess the sustainability of a specific energy project(Kolagar et al., 2020). Figure 7 below illustrates the triangular approach in energy project assessment

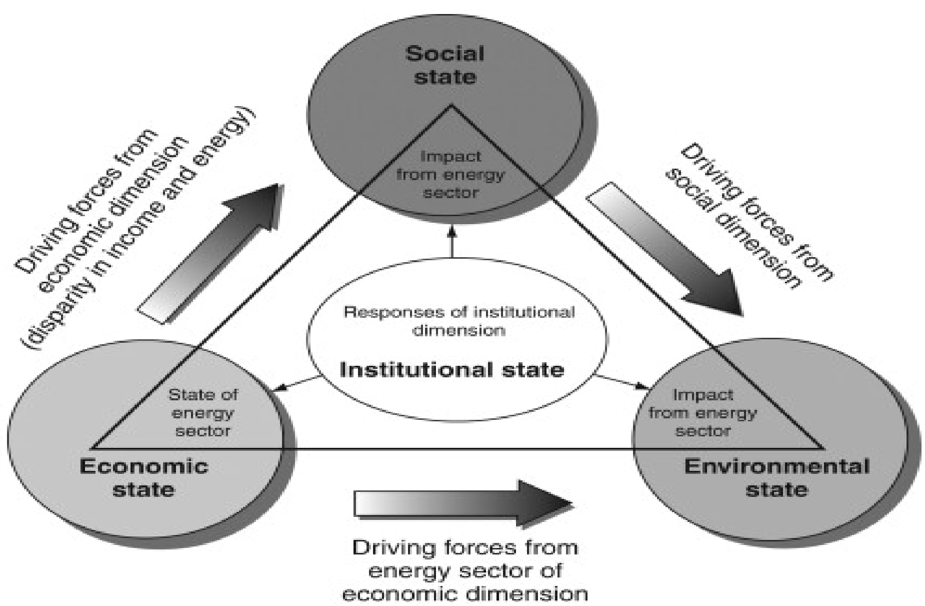

Figure 7. The dimensions of sustainability and their interrelationships(Kolagar et al., 2020)

From figure 7, it is noted that the three dimensions of sustainability are held together by the institutional state. The economic state is the main driver of social and environmental states with the institutional state playing the coordination role.

It is at the Stockholm conference, energy was identified as a source of environmental stress, thus linking energy to the environmental dimension of sustainable development. The United Nations Conference on Environment and Development (UNCED) which was also referred to as the 'Earth Summit', that was held in Rio de Janeiro, Brazil, from 3-14 June 1992 led to the Rio Declaration on Environment and Development, that had no specific reference to energy. Energy was however a central them theme in Chapter 9 in Agenda 21 on the protection of the atmosphere in which energy was identified as a major source of atmospheric pollution [1]. Agenda 21 further illustrated the need to draw a balance between economic growth, energy consumption and its environmental impacts. Although the Commission for Sustainable Development (CSD) was established by the Rio conference of 1992, it is in 1997 when energy was placed in the agenda of the Commission for Sustainable Development(Gibbes et al. 2020; Kolagar et al. 2020). Based on the progress of the Commission for Sustainable Development (CSD9,), the 2002 Johannesburg conference made direct reference to energy as crucial for sustainable development. It is in this conference that energy was addressed within the three dimensions of sustainable development i.e., economic. Social and environmental. The conference further clearly treated energy as a specific issue of concern rather than a subset of other issues as it was in the Rio Conference. There was strong and specific emphasis on energy use and its social attributes like access to high-quality energy as a basic human right. It is therefore from the Johannesburg conference of 2002 that the social dimension of energy was incorporated in addition to environmental and economic dimensions which had already been incorporated curtesy of the Rio and Stockholm conferences(Gibbes et al. 2020; Kolagar et al. 2020).

Important energy issues that affect sustainability are energy research and development, training and capacity building, and technology development and transfers. Therefore, it is the cumulative effect of the Stockholm, Rio, and Johannesburg conferences that the notion of sustainable energy development (SED) as a very important factor in the sustainable development was mooted by linking energy to the environmental dimension in the Stockholm conference, economy in the Rio conference and society in the Johannesburg conference. Over time, energy consumption and energy development have become a specific issue in the three dimensions of sustainable development.

It is Article 8 from the Johannesburg declaration that we get the most comprehensive definition of sustainable energy development. Therefore, sustainable energy development involves improving access to reliable, affordable, economically viable, socially acceptable, and environmentally sound energy services and resources that consider the national specificities and circumstances. These can be achieved through means like enhanced rural electrification ,decentralized electricity generation, greater use of renewable energy, use of clean gaseous and liquid fuels and improved energy use efficiency while recognizing the poor and vulnerable and their right of access to clean energy(Davidsdottir 2012).

1.3. Characteristics of Sustainable Energy

For energy sources and systems to contribute to sustainable development, they should possess the following characteristics.

Energy resources and systems are sustainable if they are renewable or perpetual in nature.

- Sustainable energy system should not be wasteful but efficiently produced and used with minimum resource wastage.
- Sustainable energy and energy systems should be economically and financially viable
- Energy is sustainable if the source is secure and diverse.
- Sustainable energy and energy systems should be equitable or readily accessible, available, and affordable.
- Sustainable energy development should bring positive social impacts.
- Sustainable energy should be associated with minimal environmental impacts(Kolagar et al. 2020)

Themes/Goals of sustainable energy Development

By combining the characteristics or features of the Johannesburg definition with the International Atomic Energy Agency (IAEA) definition, there ae four central goals/themes of sustainable energy development. These are.

Improving energy efficiency

This involves improvement in economic and the technical efficiency of energy systems in generation and consumption. With investment in efficient energy systems, costs will reduce as well as output from available energy resources This ca be achieved through technology transfer, research and development and good energy management practices(Kolagar et al., 2020).

i.) Improving energy security

Energy security covers the security of both supply and the energy resources infrastructure. Energy security refers to the availability of energy at all times in various forms, in sufficient quantities, and at fair prices that are affordable and predictable. Therefore, for energy to be regarded as secure, it must meet all dimensions of sustainable energy and development. Strategies to improve energy security include decentralizing power generation, wide use of renewable energy resources, investment in redundancy, diversifying energy sources, enhancing supply, more use of local energy resources. Common indicators of energy insecurity include power rationing, frequent blackouts, energy related conflicts and price instability and supply instability(Gibbes et al., 2020; Kolagar et al.2020).

ii.) Reduce environmental impact

Sustainable energy development calls for reduction in emission of greenhouse gas emissions, which cause global warming. This can be achieved through reduction in the lifecycle environmental impact of energy systems use and production or generation. Other strategies include waste recycling and treatment and adoption of clean technologies that ensure that disposal of wastes does not exceed the Earth's assimilative capacity(Kolagar et al. 2020). Decarbonization of the energy supply is a very important function in the transition to low carbon energy grid and economy. Besides technology, the deployment of a powerplant depends on the availability of resources, socioeconomic impact, and smooth integration with the existing electricity system. Energy system planners should consider all these to determine and prioritize energy projects and programs (Colla et al. 2020).

Expand access, availability, and affordability

Sustainable energy should be reliable in supply and access at affordable price or cost and quality. There is need to expand energy resources to ensure supply reliability. Goals one and two correspond to the economic dimension of sustainable development, while the third goal deals with environmental dimension of sustainable development. On the other hand, the fourth goal deals with the social dimension of sustainable development. Progress towards sustainable energy development can be measured by various indicators which are critical in the energy transition to sustainable energy (Davidsdottir 2012).

Sustainable Energy and Electricity Generation

The global warming concerns which are mainly a result of greenhouse gas emissions, sustainable development has become a serious global requirement. Sustainable electricity is generation and use of electric in a way that that does not compromise the ability of future generations to meet t energy or electricity requirements (Hollaway, 2013). It can also be defined as energy sources that do not get depleted in a time frame that is relevant to humanity and hence contribute to the sustainability of all species(Lund 2010). Sustainable Energy, just like sustainable development requires significant changes in the way things are done and the exact things that we do with effects on the industrial, production, social infrastructure, and value systems. The development of clean energy would unlock many challenges to sustainable development(Moses Jeremiah Barasa Kabeyi & Oludolapo A. Olanrewaju, 2021; Moses jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju 2022a; Kabeyi & Oludolapo, 2020b). Sustainability is a major concern today as a direct result of the serious concerns over the climate change, of which electricity generation is an important contributor(Vine 2019). Electricity is a critical product needed to support life, welfare and global sustainable development(Berga, 2016).

Currently, humanity is faced with a significant challenge to realize new sustainable development Goals (SDGs) by the year 2030 (Berga 2016; Kabeyi & Oludolapo 2020c). Sustainable development and its correlation with energy became a significant global concern and issue in the 2002 Johannesburg world summit on sustainable development(CS-UNIDO 2008). Determination of the most appropriate energy systems in in an electricity mix is considered as a strategic approach in realization of sustainable development(Ebrahimi & Rahman, 2019; Kabeyi & O. A. Olanrewaju 2020). Electricity generation systems can be assessed by a five-dimensional approach consisting of environmental, economic, social, technical and institutional sustainability as a strong measure of energy sustainability(Ebrahimi & Rahman, 2019). Therefore, sustainability in energy development seeks to achieve technical sustainability, political or institutional sustainability, social sustainability, environmental sustainability, and economic sustainability which is greatly realized by the development and use of renewable energy resources(M J.B Kabeyi, 2020). Figure 8 illustrates the 5 main dimensions of energy sustainability.

Figure 8. Dimensions of energy sustainability (M J.B Kabeyi, 2020)

Figure 8 above summarizes the main dimensions of energy sustainability particularly electricity. The main dimensions of sustainability in energy development and consumption are environmental, social, political, economic, and technical sustainability.

Technical Sustainability

Technical sustainability of electricity generation refers to the ability to meet the current and future demand in a safe and efficient manner with the use of clean sources of energy and technology (M J.B Kabeyi 2020). Unsustainable production and consumption of energy resources is the main cause of environmental damage in many organizations and countries globally(Liu, 2014). To realise sustainable development calls for changes in industrial processes and systems , in terms of the type and quantity of energy and other resources for waste management, emission control as well as product and service range or type(Krajnc & Glavic 2003). Through the development and adoption of appropriate technology, humanity can make development of energy sustainable. Engineering and technology are closely linked to sustainability, but the engineering input so sustainability must be in partnership with other interests by application of constraints to the three pillars of sustainability which are social, environmental, and economic pillars. All engineering systems, products, operations, services, and infrastructure have designed and actual life after which they should be subjected to sustainability analysis by application of three measures in order of priority. These measures are reuse, recycle and disposal (The Royal Academy of Engineering 2005).

For evaluation of energy or electricity sources, a number technical and operational indicators have to be analyzed(Dobranskyte-Niskota et al., 2009). The typical technical evaluation criteria for energy systems and sources include efficiency, exergy efficiency, primary energy ration, system reliability, maturity and safety(Şengül et al. 2015). Other important powerplant performance indicators in power plant generation are specific fuel consumption, specific emissions, power plant availability, load factor, among others.

The transformative and disruptive potential of rapid technological changes, and the danger of using primitive technologies should be avoided for a sustainable transition. Even with advanced science, technology and innovation policies, and technologies, it is unlikely to deliver progress regarding global development unless the environment nurtures learning and innovation for effective management of innovation systems. Both national and international policies should promote international technology assessment and foresight and cooperation including collaborations and technology transfer. This cross border partnerships and cooperation will facilitate rapid sustainable energy development(United Nations, 2019b).

Environmental sustainability

Environmental sustainability is concerned with managing the negative impact of energy production and use to the society and to magnify or extend the good ones. The environment should never be allowed to absorb more than it can contain, naturally or artificially(Iddrisu & Bhattacharyya, 2015). Environmental sustainability is concerned with the integrity of natural environment and its ability to remain resilient and productive in support of humanity(Kolagar et al., 2020). Environmental sustainability is further concerned with the integrity and carrying capacity of the natural environment to sustain humanity as a waste sink and source of raw materials(Mensah 2019). Thus, the environment or ecological dimension of sustainability is concerned with preservation of the environment and habitats, especially against the impacts of waste disposal, excessive consumption of earth's resources, and greenhouse gas emissions. The gases that lead global warming include, carbon dioxide, methane, and nitrous oxides. Carbon emissions in the atmosphere have increased from about 280 ppm by volume during pre-industrial times to over 400 ppm today representing more than 40% increase. In the United States, fossil fuel consumption results in average annual emission of about 5.3 billion metric tons of CO_2 into the atmosphere(Nag, 2008). The origin of these carbon emissions is from energy consumption, non-energy use and industrial processes like iron and cement production.

The typical environmental evaluation criteria of energy systems include emission levels for SO_2, NO_x, CO_2, particulate emissions, non-methane volatile organic compounds, land use and requirements(Şengül et al., 2015). The main environmental dimension indicators for energy technology assessment include: GHG emissions, environmental external costs, radionuclides external costs, severe accidents perceived in future and fatal accidents from the experience. Additional environmental indicators are land use and solid waste. Life cycle emissions of GHG emissions in kg ($CO_{2\text{-eq.}}$)/kWh are selected to assess electricity generation technologies according policies like the EU environmental policy on climate change mitigation(Streimikienea et al. 2012). GHC emissions in kg CO_2eq./kWh were selected instead of external costs of GHG emissions because of the large uncertainties related to evaluation of external costs of GHG emissions. Climate change is the dominating environmental concern of the international environ-mental political discussion of today. Global warming is not only an issue for the environment, but rather for human society, since rising global temperatures might have serious consequences on the economy and social life The indicator reflects the potential negative impacts of the global climate change caused by emissions of greenhouse gases to produce 1 kWh of electricity. This indicator was used in almost all studies on energy technologies assessment survived(Streimikienea et al., 2012).

Therefore, an environmentally sustainable energy system should maintain a stable resource base, avoiding energy resource over-exploitation, and avoid depleting non-renewable resources through development of adequate substitutes. These approaches include biodiversity maintenance, atmospheric stability, as well other ecosystem functions that are not necessarily economic resources(Jonathan 2001).

Atmospheric Temperature Changes

For the world to have a stable atmosphere, it is recommended to maintain temperature increase of 1.5 to 2^{o}C above preindustrial level which then translates to 400 ppm to 450 ppm of CO_2 equivalence (Dyllick & Hockerts, 2002). The most widely accepted climate change scenarios and projections predict annual temperature increase of 1-3.5^{o}C in coming decades based on existing scenarios(Butt et al., 2012), hence the need for more global commitment. The Intergovernmental panel on climate change (IPCC) predicted that greenhouse gas emissions (GHG) will lead to global temperature increase of between 1.1 - 6.4^{o}C by the end of the 21st Century with cities like London, Los Angeles and Phoenix having already experienced about 1^{o}C average temperature rise within a decade. The United Kingdom (UK) is expected to experience temperature rise of about 3.5^{o}C by 2050 which will also be accompanied by increased winter precipitation of up to 20% as well as increased incidences of storms (Hulme et al., 2002; Intergovernmental Panel on Climate Change(IPCC), 2007). This predicted temperature rise is higher than the target set by the Paris Conference of 2015 (COP21) of 2^{o}C above pre-industrial levels (Berga, 2016; Lu, 2017). These statistics paint a picture of a world that is already missing its targets that are necessary to save mother nature and humanity

Ecological Sustainability

Ecologically sustainability requires organizations to use only natural resources that are consumed at rates that are below their natural reproduction or replenishment rates or at a rate less than the development rate of substitute products or resources. They should also ensure that emissions which have potential of accumulation should not be allowed to accumulate at rates that are more than the capacity of the natural removal or absorption from the ecosystem system(Kabeyi, 2019a, 2019e; M J B Kabeyi, 2020a). Sustainable organizations should never engage in actions or activities that degrade any part of their eco-system(Dyllick & Hockerts 2002). Natural resources should be consumed by mankind at rates that allow them to replenish themselves (University of Alberta, 2015). Therefore, environmentally sustainable systems should maintain a stable resource base free from over exploitation of energy resources. Ecological sustainability also advocates for maintenance of biodiversity, stability of the atmosphere, and other economic and non-economic ecosystem functions and resources (Jonathan, 2001), while non-renewable resource substitution by renewable sources is a solution for the depleting ad polluting resources like fossil fuels namely petroleum, coal, and gas.

Environmental management and protection are a significant indicator of peoples' culture, values, and ethical principles. Ethics involve making decisions based on acceptable values. This calls for social movements that constitute useful sources of cultural values and environmental movement to influence the environment is managed(Kabeyi, 2018a, 2018c). Therefore, sustainable environmental management is a result of multiple actors and factors. Environmental management for sustainability is concerned with control of interaction with the environment to protect and enhance human health and welfare together with environmental quality. Energy production, conversion, delivery, and end use can have serious environmental consequences to air, land and water quality which are important for preservation of human life. These environmental issues related to energy are discussed below(Kabeyi & O. A. Olanrewaju 2020).

Water Pollution

Energy-related processes impact on water through discharge of water polluting solid and liquid wastes, thermal pollution from waste process heat, and excessive consumption of freshwater, and negative impact on aquatic life. Chemical contaminants like acids from mining operations, and discharge of coal ash to water bodies, radioactive wastes from nuclear power plants as well as oil spills from diesel power plants are common scenes from power plants(Raja et al. 2006; Rajput 2010). Although considered as gaseous and hence air contaminant, Carbon dioxide (CO_2) causes acidification of oceans with serious negative impacts on aquatic life. Process improvements and technology can help mitigate this pollution of water from energy related activities(Nag, 2008; United States Department of Energy 2015). Buried nuclear wastes can cause contamination of underground water source. Energy-related atmospheric emissions of conventional pollutants such as particulates, sulfur, and nitrogen compounds have been reduced through improved combustion strategies and exhaust scrubbing while transition to cleaner energy sources is also proving to be effective (M J.B Kabeyi, 2020; Nag, 2008; Raja et al. 2006; Rajput, 2010). Used brine can also contaminate surface water in geothermal powerplants in powerplants with no reinjection(Kabeyi, 2019c; M J B Kabeyi, 2020b). Some technologies may not be water polluting but the process through which the lant and equipment are producing may be highly polluting.

Land Contamination

Energy and power generation related activities contaminate or pollute land in various ways**.** Land pollution takes many forms like deposition of atmospheric pollutants with precipitation, direct discharge, and accumulation of pollutants like coal ash from coal power plants. Oil spills from diesel power plants, soil extraction or excavation for fuel mining and production or associated with energy plant and infrastructure siting and development. Although regarded as clean power sources, wind and solar power plants occupy huge tracts of land which may no longer be used for other economic activities like farming and human settlements. Cases of induced seismicity have been experienced in geothermal power development and generation which affects land use (Kabeyi, 2019b; M J B Kabeyi, 2020b; Kabeyi & Oludolapo, 2020a). Radioactive wastes from nuclear power plants may also be buried underground rendering the area useless for other economic activities (Rajput, 2010). while liquid and gaseous emissions and effluents still must be handled by nuclear power plants. Buried nuclear wastes can cause contamination of underground water source. Energy-related atmospheric emissions of conventional pollutants such as particulates, sulfur, and nitrogen compounds have been reduced through improved combustion strategies and exhaust scrubbing while transition to cleaner energy sources is also proving to be effective (M J.B Kabeyi 2020; Nag, 2008; Raja et al. 2006; Rajput 2010). Lack of reinjection in geothermal power plants can lead to land contamination by the used geothermal fluid(M. J. B. Kabeyi & A. O. Olanrewaju, 2020; Moses Jeremiah Barasa Kabeyi & Oludolapo A. Olanrewaju 2021).

Economic Sustainability

Economic sustainability in energy and electricity production and use refers to the ability to meet demand in a cost-effective manner. It also a measure of access to requisite financing for energy resource development. The cost-effective operation will ensure that the energy system is s economically viable and feasible and hence makes the investment attractive to investors and financiers (M J.B Kabeyi, 2020). All economies are made up of markets where transactions are made. The main activity in an economy is production of goods and services, distribution and consumption(Mensah, 2019). Therefore, economic dimension of energy sustainability is concerned with the viability of individuals and organizations, products, and services in production and consumption of energy or electricity, distribution, and interactions.

Economic sustainability seeks to maintain the operational stability in terms of liquidity and cash flow and ensure fair or reasonable income and benefits to investors and other stakeholders in energy systems(Dyllick & Hockerts, 2002). Electricity is the most multipurpose energy carrier globally, and therefore it is highly linked to human and economic development (Bazmi & Zahedi 2011). For economic sustainability to thrive, organizational policies and operations should not retard economic progress, development, or affluence of society(Hasna, 2007). It is through economic sustainability that humanity can maintain independence and have unlimited access to the required energy resources. Economic sustainability is realized from energy systems if they remain intact while activities and processes are equitably accessible to all to secure their livelihoods in a fair manner (University of Alberta, 2015). Therefore, energy or electricity system must continuously produce goods and services to manage debts, pay bills, pay workers ensure sectorial balance with stable agricultural and industrial production (United States Department of Energy, 2015). Energy systems and organizations should remain profitable and useful from one generation to another generation(Kabeyi 2018c). Therefore, this implies that energy systems are economically sustainable if they are operated profitably by investors or organizations.

Energy costs are embedded in every commodity and service in an economy and therefore the economy requires better and efficient energy technologies to reduce energy costs leading to affordable electricity. This will enhance the level of economic activities through better supply reliability, reduced import bill, and a bigger market for energy goods and services. This leads to higher gross domestic product and balance of payments at a macroeconomic level(United States Department of Energy,2015). The various elements of economic dimension of energy sustainability of include corporate sustainability, energy costs, supply disruption loses, energy import bills, energy technology and service market.

Renewable energy projects make use of local labor from rural areas, businesses, local material and business, local investors, and other services. Therefore revenue from renewable energy electricity revenue is invested back to local communities in form of taxes, payments for materials and labor as well as profits to investors which leave more economic benefits than imported fossil fuels or imported grid power (Kumar, 2019). Different renewable energy sources have different socioeconomic value. For example, biofuel projects create more jobs as compared to jobs created by solar and wind powerplants which gives the different projects a unique rank in socioeconomic evaluation of energy options. The cost and price of generated electricity is another important economic aspect of power generation projects and has a bearing on electricity sustainability (Akella et al., 2009).

In economic evaluation of energy systems, typical evaluation criteria include total cost of investment, operation and maintenance cost, fuel cost of generation, electricity cost, net present value (NPV), service value and equivalent cost of the energy system(Şengül et al., 2015). The Economic dimension in sustainability assessment of energy technologies and projects is significant since energy or electricity supply cost influences technology adoption and penetration. Indicators that address economic dimension of energy sustainability assessment in electricity and heat generation and supply include the private or investors costs involved, the fuel price increase sensitivity, energy or plant average availability factor, costs involved in grid connection, energy or plant peak load response, and energy security of supply. Very important economic investment indicators are private costs, availability factor and costs of electricity grid connection(Streimikienea et al., 2012). Goods and services should be produced in a continuous manner in an economically sustainable system to be realized. should produce goods and services continuously, to maintain sustainable levels of debt, and (Jonathan, 2001).

6.1.1. Energy Costs

Several factors influence the cost of energy and electricity and hence the price paid by consumers. These factors include the type of primary energy commodity used, availability of supplies or resources, primary sources price or cost, the capital costs of the power plant and operating costs incurred to convert or process the supplies into energy services like electricity, and prevailing energy demand. The variation in energy cost for various sources of energy leads to market competition among energy resources and services, with alternatives sources of energy. Unfortunately, the costs associated with energy security and environmental factors are often not fully included in the market price of energy sources. Reduced energy costs generally contribute to improved performance in many sectors of the economy, hence the need for low-cost energy and electricity supply. The reduction in cost of solar and wind power generation can significantly affect the competition with other, more traditional generation options like fossil fuels(United States Department of Energy, 2015).

Energy systems respond to changes in input price and technology at different rates to in the energy sector and markets. The price of energy responds to the supply and prevailing demand which is dynamic. The factors influencing price include inventory level, level of economic activities, political factors, environmental factors, and market speculation which can drive market price volatility. These instability and volatility in energy price makes planning complicated and difficult, and hence negatively impact the entire economy. It is desirable to have a diversified portfolio comprising of many different sources of energy supply and enabling technologies to provide feasible options that can allow one to hedge the risk of being dependent on a single energy supply (United States Department of Energy, 2015).

Energy related disruption and losses

Energy disruptions can occur on the supply side, consumer side or transmission and distribution infrastructure any time, whether planned or not. Any electric power outage causes substantial economic costs and losses to the businesses and activities most of which depend on electricity. As an example, study by Lawrence Berkeley National Laboratory in 2006 on the cost of power outages estimated that disruptions to the U.S. electric power system cost between $22 to $135 billion per year with common causes identified as weather-related events like falling trees, and equipment failures like transformer failures. In another study, it was found outage-related costs ranging from $20 to $50 billion per year for weather-related outages alone. These losses are worse off if damages due to extreme weather events like Hurricanes are considered. The solution to this significant loss is improvements to the transmission and distribution systems(United States Department of Energy 2015). Sustainable engage should not only be affordable but reliable in supply, generation, and transmission.

Energy Import Liabilities

Energy business has significant impact on the balance of payment positions for importing and exporting countries for example the US spent approximately $190 billion in 2014 on petroleum imports. Oil importing countries must content with energy insecurity and fluctuating price and supply of petroleum. Electricity can also be imported and exported between countries leading to sharing of resources with resource rich countries especially with desirable renewable and low carbon sources like hydro and nuclear. Reducing dependence on energy imports reduces the impact of supply disruptions while promoting local investment in sustainable energy options (United States Department of Energy, 2015).

Energy Technology Markets

Electricity generation and distribution is a big business in all countries while production and export of energy resources like fossil fuel sustains many countries' economies with some almost entirely dependent on oil and gas exports. Other commercial primary resources include coal while some countries have relied on charcoal business to generate significant revenue. Export of energy production equipment like generators, turbines, boilers, and other plant equipment represents a substantial market opportunity for many countries like the United States and often generate high-value jobs. The International Energy Agency (IEA) predicts that clean energy will supply between $7 trillion and $10 trillion investment in electricity generation of which $6 trillion will be renewable sources and $1 trillion in low carbon nuclear power generation over between 2015 and 2025. It is observed further about two-thirds of this investment will be done in emerging economies. Additionally, energy efficiency investments will account for a further $8 trillion of investment (United States Department of Energy 2015).

Social sustainability

Social sustainability is concerned with the rights of the community as measured by the level of social acceptance and access to the energy resource and systems by the people (Iddrisu & Bhattacharyya, 2015). Social sustainability is the ability to preserve desirable social values, institutions, traditions, and social characteristics of the society before and after a project or an intervention. It is also concerned with social justice and therefore addresses aspects like labor practices, variance in production standards, and promotion of equity among all people(Kabeyi, 2018b, 2019a, 2019d). Social sustainability can be achieved by the selection and development of technology and power plants that provide adequate power and employment to local communities and that don't interrupt or interfere with their established way of living and value system (M J.B Kabeyi, 2020; Kolagar et al. 2020; Liu 2014). Therefore, social sustainability implies that people are important because development is basically about the people themselves. Principles that should be applied in energy development to realize social sustainability include accountability, empowerment, participation, cultural identity, and institutional stability(Mensah 2019).

At institutional level, sustainability is grounded in environmental initiatives which were sometimes referred to as green corporate initiatives. This is the ability of an organization to endure, take care of the needy in society and ensure institutional responsibility for greater good of the human society (Samaras et al., 2019), by taking care of the world's most vulnerable people in society. Any effort to achieve financial gains for the few while ignoring the needs of the majority is no longer acceptable, reasonable, productive, or justifiable(M J B Kabeyi, 2020a). Therefore, socially sustainable organizations attempt and succeed in adding value to the communities within which they operate or do business. This is achieved by increasing the human capital base of individual partners and social capital of the community. Organizations should manage social capital in a way that stakeholders do understand the objectives and motivations for general agreement and cooperation (Dyllick & Hockerts, 2002). Therefore key requirements for social sustainability of energy transformation is openness and democracy in the process (Miller et al., 2013). Therefore, engaging in community social responsibility (CSR) activities is a strategy for increasing social sustainability of energy activities.

Social sustainability assumes two types of sustainability i.e., social capital and human capital. Social capital is concerned with quality of public services like good education, water, infrastructure or a supporting culture and value system. Human capital is primarily concerned human skills, level of motivation and loyalty of employees and business partners in their own capacity (Dyllick & Hockerts, 2002). Therefore, human capital is an intrinsic phenomenon of an individual or individuals while social capital is concerned with communal or common physical projects, infrastructure or facilities meant to improve the quality of human beings in each social system. This implies that sustainable energy systems should have a positive impact on both human and social capital of the society.

Individual organizations have a critical role to play to ensure social sustainability of energy systems during the energy transition. Social sustainability requires organizations to act in a manner that creates welfare to society and all its people and should be ready to take responsibility for their actions (Mohamed et al., 2020). A socially sustainable organization should internalize the social costs, develop the capital stock, exceed the social carrying capacity, enhance self-renewal of natural systems, nature openness, accountability, and democracy, enhance human choices and practice fair distribution of available but scarce energy and other resources among all stakeholders. It is necessary that social sustainability should preserve human rights and human dignity and guarantee equitable access to necessities which leads to a healthy and secure society. Communities that are healthy have fair leadership which ensures that personnel, labor, and cultural rights of all are respected to the later (University of Alberta, 2015). Therefore for energy resources and electricity systems to be socially sustainable, they should be characterized by equity, reliable supply of social services, address gender equity, facilitate political stability, address accountability issues, and nature participation in their governance systems (Jonathan, 2001). Social sustainability requirements call for energy practitioners, organizations, and countries, local and international organizations to go beyond just energy solutions and ensure holistic approach in as far as energy transition is concerned. Energy transition should address human physical and health, system and human safety, human rights, and dignity for sustainable energy development to be achieved.

Energy policies necessary to realize sustainability should be guided by a mixture of robust, objective, empirical and theoretical principles that consider the impact not just to the current generation, but equally on future generations. Energy resources and electricity systems should consider socio-technical impacts on man and machines for them to be socially acceptable. Adoption of new electricity or energy technologies should bear in mind that systems are operated by man and should therefore be acceptable and comfortable by design and adequate capacity building should be done for man to be comfortable and therefore embrace new ways and systems. The impact of the technology change or acquisition on current and future financial systems, school system, labor market composition, organizational culture and political aspirations of the people should be considered in the energy transition if it has to be sustainable and avoid failure or negative perception by the people(Miller et al., 2013). This implies that man is a very important aspect of the energy transition and should be at the center of the transition and be involved using various participatory methodologies, otherwise the transition may never succeed.

Any social evaluation of energy systems should consider social acceptability, expected job creation, and other social benefits of the energy systems(Şengül et al., 2015). Significant social indicators for energy and electricity technologies are related job opportunities, health effects, food safety and security risk and work-related accidents and fatalities. Technology specific job opportunities in person-year/kWh indicator are based on the average amount of labor used to produce a unit of electricity(Berga, 2016; Lu, 2017). The quality of electricity or energy related work is addressed by

Work Quality indicator is based on knowledge and training of average worker in each technology chain, using an ordinal scale indicator (Streimikienea et al., 2012). A system is said to be socially sustainable if it guarantees distributional equity, provides social services like education, health, guarantees gender equity as well as political accountability and adequate public participation of stakeholders(Jonathan, 2001).

Therefore, social sustainability of the energy transition is concerned with the value to community, democratic participation, direct benefits through addition of human and social capital, job creation and other community benefits through activities like corporate social responsibility and respect for local customs, traditions, and beliefs.

Political and Institutional Sustainability

The development of new energy technologies, new business models, and new policy priorities and frameworks need new market participation and control models and rules and regulations which require new governance and new institutional design(De, 2021; Lenhart & Fox, 2021). Transition historical studies show that whereas technological innovations and market actors are the main drivers of change, extensive studies claims that it is governance systems that influence the distribution of the benefits of new technologies to the society which is an important requirement of sustainability(M J.B Kabeyi, 2020; Kuzemko et al. 2016). The road to the global low-carbon transformation should deal with the climate crisis is within reach, but this requires political actions from world leaders. There is need for action along multiple approaches and models globally that can be scaled up and adapted to suit specific national prevailing circumstances. Cost-effective a low-carbon technologies are available in many fields with several under research but the rate of adoption is still a serious concern because governments need to put in place the right policies, regulations and a facilitating legal framework for faster and successful adaption (Krzywda et al. 2021; Watson et al., 2014). Political or institutional dimension of energy sustainability is concerned with governance of sustainable energy transformation at all levels. This is achieved by setting and implementing policies and regulations with different political institutions influencing governance choices(Kuzemko et al., 2016). This implies that the political dimension of energy sustainability is concerned with the strategic planning and definition of the energy system and related systems and processes. Therefore, political sustainability concerns address the future structure and indicates some issue on political stability and foreign policies of the energy system (M J.B Kabeyi, 2020). For development to be sustainable, there is need for adequate management of the tradeoff between social equity, protection and integrity of the environment, real economic development and progress and preservation and use of natural resources for equitable use by all (Robyns et al., 2012). This can only be achieved effectively when we have the political will from all if not many nations and groups that have power to influence energy policy (Kabeyi, 2019a).

The institutional dimension of sustainability defines the role of local participation in the control and management of energy resources and energy systems(Kabeyi, 2019a, 2019d). The institutional dimension embodies elements like local ownership, participation, local contributions, local skill base, local policy and regulation, protection of investors and consumers and sharing of resources and benefits accruing. This dimension is the one that defines the system structure and framework of processes, systems and policy decisions which affect the project or investment(Iddrisu & Bhattacharyya, 2015; Kolagar et al., 2020). There is evidence that highly or adequately institutionalized countries with efficient and effective energy related institutions are more successful in managing the energy transition. This is because the institutions encourage innovation, efficient resource allocation and set desirable policy, legal and financial measures and instruments which are enables of sustainable energy transition(Inglesi-Lotz, 2021).

Politics and sustainable energy transition

Energy activities, products and services constitute big business globally. In 2015, 4 out of 8 top Fortune 500 companies, were energy related companies like Exxon Mobil, Chevron, Phillips 66, and General Electric. Therefore, energy represents a big portion of global economy and therefore it affects jobs, people's incomes, company performance, profits, and personal or individual economics. Within these dynamics, politics become important especially as an enabler of business through various instruments at their disposal. Internationally, government subsidies have helped the development of new technology for solar and wind power. Many governments subsidize the oil and nuclear power industries which complicates the viability of renewable energy resources and technologies (United States Department of Energy 2015).

Politics play a leading role in the coal industry which continues to survive and thrive in many countries like the United States because of exemptions from federal pollution regulations making its use competitive. The same is true for hydrologic fracturing or fracking, which has survived in the US because of the 2005 Clean Water Act. The US government also subsidizes pipelines and supports military actions in the Middle East as a strategy to ensure a stable and reliable supply of fossil fuels. Energy has also been a leading cause of most political tensions between countries. These tensions or conflicts shape the decisions all countries make about their energy resources which ultimately affects their electricity mix so as to manage costs, security and environmental concerns besides shaping international relationships (Dufour 2018).

Energy policies, regulations, and governance

Governments should strive to meet the growing energy demand but also meet environmental requirements. To realize these demand and sustainability challenges, Governments should develop regulations and policies that seek to meet the growing energy needs and concerns over emissions and global warming. It is necessary to develop sustainable energy policies to provide relevant and suitable policy recommendations for end-users(Lu et al., 2020). Policymakers should develop sustainable solutions and a conducive environment for a sustainable energy transition. Good governance in the energy sector is an important tool to realise climate change mitigation by investing in sustainable measures and projects. There is need for public intervention by putting in place what is considered as a conducive energy transition's regulatory framework, Renewable energy projects and other sustainable energy investments, just like any other investment, require political stability, proper regulatory frameworks, good and effective governance and secure property rights(Inglesi-Lotz, 2021).

Energy policy issues are political in nature, and act as instruments through which governments can influence sustainability in the society. Governments should develop energy policies which can alter consumption habits and patterns, reduce fossil fuel dependency and environmental conservation and protection while stimulating investment and development of clean energy technologies. Interest groups represent interests from energy conservation proponents to nuclear power opponents (Marcus, 1992). Interest groups representing various groups and stakeholders from energy conservation to nuclear power opponents need to be heard during policy formulation on sustainable electricity(Marcus, 1992). Energy policy seeks to establish security of supply, energy affordability, and minimum impact on the environment.

Institutions in energy transition generally refers to the formal and informal rules and the their enforcement (Inglesi-Lotz, 2021). The quality of these institutions is measured in terms of ability to create a conducing environment characterised by the following indicators and dimensions.

i.) Voice and accountability

This refers to the extent to which the people in a country can choose and challenge the government of the day which limits executive authority.

ii.) Peace and political stability

The citizens of a country have no incentive to invest in their future in environments of political instability or civil strife. This therefore makes sustainability concerns secondary to the need for immediate survival.

iii.) Government effectiveness

Government effectiveness is the quality of public services and the degree of freedom or independence from political pressures and interference. This creates an enabling environment for private sector investment in energy.

iv.) Regulatory quality

Regulatory quality is the ability to formulate and implement appropriate policies and regulations that facilitate private sector growth and development. This requires that government lays down fair and uniform rules of economic engagement.

v.) Rule of law

Investment in sustainable energy requires suitable laws governing quality of contract enforcement, private and public property rights, effective police, and courts for arbitration and the enforcement of the rules of society.

vi.) Control of corruption

There is need for a strong anticorruption prevention for more the more economic success as a Corruption inhibits investment and increases the cost of doing business and lowers competence and efficiency of performance which in itself and indicator of lack of sustainability(M J B Kabeyi, 2020a).

vii.) Ease of doing business

This is a measure of the multitude of aspects that influence the extent to which the regulatory environment is facilitates business operations. Investment in sustainable renewable energy projects can delayed or abandoned by too complex and lengthy bureaucratic procedures and corruption(Inglesi-Lotz, 2021).

A sustainable energy transition calls for the design of an appropriate market structure for proper performance of the energy sector in terms of prices, energy efficiency, supply, and technological innovation. Governance mechanisms directly influence the market structures and influence investment decisions. Therefore, bad or improper market structure designs and policies can lead to higher costs of the energy sector unnecessarily which impacts negatively on the welfare of consumers(Inglesi-Lotz, 2021).

Energy security, risks, and system resilience

Energy security generally refers to low probability of damage to acquired values. Energy security is best defined by the 4 As of energy security which refer to availability, affordability, acceptability and access to energy resources and systems(Cherp & Jewell, 2014). Energy security is therefore the degree of vulnerability on vital energy resources and systems which is influenced by the degree of exposure to energy related risks, its resilience and links to important energy and social systems. Energy security issues emerged in the early 20th century with respect to the supply of oil to the military more so in the frontline. Academic reflections on energy security emerged in 1960s and became real in 1970s with the oil crisis. It remerged in the 2000s with concerns over rapid demand growth for energy in Asia and gas supply disruptions in Europe and the current pressure over emissions and global warming concerns(Austvik, 2016; Cherp & Jewell, 2014).

Energy systems are entangled with human and national security with reliability concerns shaping public opinion and policy as well as political decisions and agenda with implications on the economy and political systems(Austvik, 2016). It is the desire of everybody and every nation to have uninterrupted supply of vital energy services and hence, energy security is a priority for all nations (Jansen & Seebregts, 2010).. The security concerns are robustness i.e., resource sufficiency, system reliability, stability, and affordability; sovereignty which include protection from internal and external threats; and resilience which is ability to withstand disruptions of energy systems. For many countries, energy insecurity means lack of self-sufficiency and having aging infrastructure, while insecurity issues among developing countries additionally includes lack of adequate capacity, high energy intensity, and high demand growth that is more than ability to supply. For low-income countries, multiple vulnerabilities overlap, making them seriously energy insecure (Jacobs et al. 1987).

Energy security is a very important policy driver with privatization of the electricity sector being used as a tool to secure cheaper energy supplies in some countries in the short term. However, this has led to contrary effects in some places because of stiff competition, resulting in delayed and deferred development of power plant and infrastructure caused by prolonged uncertainties on viability(Bazmi & Zahedi 2011). Renewable energy sources have the potential to help nations become independent from foreign energy supplies and mitigate risks from conflicts and other disruptions to vital energy resource supplies because most of them do not rely on imports unlike fossil fuels sources(Ölz et al. 2007). A typical example of an energy conflict involved the expansion of the existing pipeline between Germany and Russia through the Baltic Sea. This caused international disputes with the US warning Germany with sanctions (Dettmer, 2019). In this energy project, countries like Poland and Ukraine heavily criticized the pipeline, fearing that Russia would use it for political gain and escalate regional conflicts through arming Eastern European countries (Gurzu 2019). This is because of the concern that the pipelines can deliver gas to German directly and hence by-pass Ukraine and thus escalate the conflict with Ukraine.

In another case of energy insecurity, the first oil crisis in 1973 brought about a reduction of about 30% in the supply to of oil to Japan leading to Japanese economic downturn and recession in 1974. These reminded policy makers in Japan that energy supply is a serious security issue and should be managed (Cheng, 2009; Mihut & Daniel, 2013). The case was similar in South Korea which was also seriously affected by the first and second oil shocks of 1973 and 1979(Azad, 2015; Miller et al. 2013). The supply shocks demonstrated that energy supply and national security are seriously intertwined. In 2011, the Tohoku earthquake in Japan brought about massive disruptions to energy supply after Japan was forced to shut down its nuclear power plants after the nuclear accident at Fukushima Daiichi power plant leading to increased use of fossil fuels. This caused significant increase in fossil fuel demand and supply(McCurry 2015; U.S. Energy Information Administration 2020). Today, Japan and South Korea have shifted their electricity generation from oil based and to liquefied natural gas and coal which is steal a fossil fuel but with less environmental impact(Korea Energy Economics Institute (KEEI), 2017; Ministry of Economy 2018).

In yet another case of energy insecurity, Taiwan, experienced a massive power outage in the northern half of the island in 201 that lasted five hours causing an estimated damage of three million US dollars. Although this was partly blamed on human error, and structural challenges within Taiwan Power Corporation, a critical analysis showed that operating electricity reserves had significantly reduced from 6% to just 1% within one week to the blackout (Yu, 2017). Therefore, adequate energy planning has an important role to play in energy supply security and that unreliable or insecure energy system can be quite destructive and costly to any economy.
There are several energy related risks to national energy and electricity security, and can be broadly categorized into physical, cyber, economic, and conflict-related risks although with significant overlaps among these categories. Energy technologies must be robust and resistant to these vulnerabilities if they must be sustainable and secure.

Physical energy risks
Energy security risks are related to the damage and disruption of energy supply, energy storage, and delivery infrastructures. Several energy infrastructure and assets are susceptible to damage and disruptions. Energy infrastructure include the electrical grid infrastructure system, pipelines for oil and gas, and rail transport network and infrastructure, as well as road and marine systems. Examples of damages to the infrastructure include Hurricane Sandy effects and the attacks on substation facilities and power plants as a result of extreme weather with climate change raises these risks (United States Department of Energy 2015).

Cyber security risks

Cyber security refers to vulnerabilities that compromise the computer-based systems and related operations and functions like data inputs, data analysis, and data processing, the real time operation and coordination of electricity supply systems, energy delivery, and end-use systems control in smart grids. There is need to validate and manage all data inputs, monitor the systems for intrusion, and the need to address other vulnerabilities which come with challenges of maintaining the integrity of these systems. Electricity networks encounter cyber security threats which increase with access to the internet and other computer supported operations as in the case of the smart grid (United States Department of Energy 2015).

Economic energy risks
Economic energy security risks are related to resource supply and price shocks like the oil crisis of 1973 and 1978. Energy resources that are traded internationally are particularly subject to price and supply fluctuations due to various reasons that include civil war, international war, economic sanctions, and deliberate supply control. The price and supply shocks create uncertainties for energy-dependent businesses, which then invest in energy security measures including research and development of renewable and sustainable energy systems. Supplier related risks include price and supply manipulations. Manufacture of complex energy infrastructure components is often dependent on global supply chains which can be adversely affected by long lead times, long-range shipping logistics, and price volatility (United States Department of Energy, 2015).

i.) **Conflict-related energy insecurity**

These are risks that are related to unrest in foreign countries as well as energy fueled domestic or local conflicts. International security risks include those that involve unrest in locations that are critical to global energy supply(Austvik, 2016). They include conflicts in the Middle East which seriously disrupt the supply of petroleum resources. These conflicts also cause deaths, economic meltdown, and environmental disaster like oil spills and destruction of oil resources by enemies in conflicts(United States Department of Energy, 2015).

In many countries, conflicts over energy resources are a common denominator. In most of these conflicts, prevailing historical differences and injustices among neighbors has been cited in various areas like religion, tribe, race or even clans and political inclinations. For example, in Syria and Iran, the conflicts appear like they are religious in nature between Sunnis, Shiite Muslims, Kurds, Turkmen, and others while. In Nigeria, it may appear as a conflict is over energy between Muslims, Christians, and other traditional groups, while in the South Sudan, the conflict looks like just differences between the Dinka and Nuer tribes. In Eastern Europe, conflicts in Ukraine, are between Ukrainian loyalists and Russian speakers aligned with Moscow. A deep scrutiny of these conflicts highlighted place energy at the epicenter of the differences, hence the reality is that these conflicts are struggles for control over the principal source of national income which is energy(Dufour 2018; Marcus 1992). Therefore, it is only through proper energy resource management that social, political, and economic conflicts can be avoided or resolved. Hence, for energy to be sustainable, governments and groups have a duty to maintain peace and stability and prevent or manage existing and potential energy conflicts within their political environment.

Corporate sustainability

This is an extension of institutional and political dimension of energy sustainability(Kabeyi & O. A. Olanrewaju, 2020). Organizations and individuals create social impacts that are both positive and negative, through their operational activities. Societies rely on organizations for individual and common good and benefits like employment and social infrastructure, while organizations or corporations need societies to provide workforce and other critical inputs like raw materials to sustain their operations. While we have the interdependence between organizations and society, it is only a healthy and positive society that will create good workers sought organizations (Tharp 2012). Individuals within the community or society play a significant role in developing sustainable situations and circumstances but organizations can influence this by acting sustainably in their operations and relationships with society(University of Alberta, 2015). Since there is mutual dependence between institution or organizations and society, there is need to have the principle of shared value while making choices and decisions. Sustainability demands for responsibility and facilitates human creativity to develop innovative ways that will further protect the shared environment, respect for all, and empower stakeholders. For organizations, sustainability is important because it creates value and provides them with competitive advantage and leaves a greater positive value to society and stakeholders as well(Nawaz & Koç 2019).

Energy sustainability programs and activities should facilitate the bridging of the gap between laws and the requirements of good business practice, which include prevention of exploitation, transparence, and accountability to all stakeholders in business or a given system under consideration. This calls for proactive risk identification, assessment, mitigation, and management. This makes sustainability a necessary value and an integral business goal and objective of all organizations including energy companies. Long term success of business operations should incorporate social, environmental, and supply issues in all their undertakings with suppliers, customers, and all other stakeholders. This in return adds value to the respective organizations in terms of corporate reputation, brand visibility, value and equity, better risk management, easier access to capital, talent attraction and retention and higher profitability and return on investment (Kanter 2010).

Corporate sustainability involves the integration of the economic, ecological, and social aspects in business practice and operations(Dyllick & Hockerts, 2002). The consumption of goods and services is pivotal to enhanced organization's operational efficiency because sustainable use of goods and services leads to reduced generation of waste during productive operations. The general objective of sustainable corporate development is to realize economic, social, and low carbon sustainability by companies. By embracing sustainable innovation practices, organizations can reduce adverse social and economic impacts of their operations which leads to better corporate performance (Kabeyi & Oludolapo, 2020d; Mohamed et al., 2020).

Environmental sustainability of an organization is an important element of corporate sustainability since it is associated with social consequences of business activities and the environment (Darkwah et al., 2018; Mohamed et al., 2020). An organization that is environmentally proactive should accommodate their stakeholder concerns which leads to better corporate performance and profitability. Environmentally friendly practices are positively related to corporate sustainable performance because of low carbon innovation attitude(Darkwah et al., 2018; Mohamed et al., 2020; Rosen, 2009). Therefore, socially responsible corporate behavior often affects environmental sustainability.

Corporate sustainability strategies incorporate sustainable development principles into business activities and mediation of the relationship between environmental, social sustainability and technology in organizational operations. Nurturing creativity helps to increase environmental, social, and economic efficiency and effectiveness by organizations and in the process, it facilitates advancement of environmentally friendly measures. Therefore, creativity impacts green innovation within organizations and so should be encouraged (Mohamed et al., 2020; Moriarty, 2019; Musango et al. 2011).

Various elements have an impact on corporate sustainability which also affects energy sustainability. Energy activities constitute a very important social enterprise with 9 out of 12 most capitalized companies globally engaging in energy business (Miller et al. 2013). Organizations that are economically sustainable have guarantee that they always have sufficient cashflow to ensure liquidity while at the same time they produce above average returns to the investment. Organizations that are ecologically sustainable consume natural resources at a pace lower than the resource reproduction or substitution and they do not pollute the environment with emissions that accumulate beyond the capacity of natural systems to absorb and assimilate them(Kabeyi, 2018c, 2019e; Kabeyi & Oludolapo 2020a 2020c). They also do not engage in ecosystem degrading services. Socially sustainable companies usually add value to the communities where they operate through increment of the human capital of partners. They also improve the societal capital of surrounding communities and are transparent in their activities and operations.(Dyllick & Hockerts 2002). Therefore, corporate sustainability is a critical part of the wider energy and global sustainable transition.

Therefore, institutional dimension is a very important dimension in determining and influencing investment, competitiveness, prices, investment, and performance of energy sector. The political function sets energy sector institutions, policies and regulations that govern the energy sector and therefore directly influence choices and performance of the energy transition measures and investment.

7. Results and Discussion
8. Conclusions
9. Declarations

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Authors Biographies

Moses Jeremiah Barasa Kabeyi is currently a doctoral researcher in the Department of Industrial Engineering at Durban University of Technology. He earned his B.Eng. degree in Production Engineering and MSC in Mechanical and Production Engineering (Energy) from Moi University, in Kenya, MA in Project planning and Management from University of Nairobi, in Kenya and Diplomas in Project management, Business management and NGO management respectively from The Kenya Institute of Management. He has worked in various factories including sugar manufacturing at Nzoia Sugar Company Ltd, pulp and paper at Pan African Paper Mills EA Ltd, and power generation at the Kenya Electricity Generating Company (KenGen) in Kenya, in an industrial career of 16 years before moving into teaching. He has taught in various universities in Kenya including University of Nairobi, Technical University of Mombasa, and Egerton University and currently on study leave. His research interests are power generation, fuels and combustion, internal combustion engines and project management and sustainability. He is registered with the Engineers Board of Kenya (EBK) and Institution of Engineers of Kenya (IEK) and has published several journal papers.

Oludolapo Akanni Olanrewaju is currently a Senior Lecturer and Head of Department of Industrial Engineering, Durban University of Technology, South Africa. He earned his BSc in Electrical Electronics Engineering and MSc in Industrial Engineering from the University of Ibadan, Nigeria and his Doctorate in Industrial Engineering from the Tshwane University of Technology, South Africa. He has published journal and conference papers. His research interests are not limited to energy/greenhouse gas analysis/management, life cycle assessment, application of artificial intelligence techniques and 3D Modelling. He is an associate member of the Southern African Institute of Industrial Engineering (SAIIE) and NRF rated researcher in South Africa.