World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:17, No:6, 2023

# Evaluation of Sustainable Business Model Innovation in Increasing the Penetration of Renewable Energy in the Ghana Power Sector

Victor Birikorang Danquah



***Abstract*—**Ghana's primary energy supply is heavily reliant on petroleum, biomass, and hydropower. Currently, Ghana gets its energy from hydropower (Akosombo and Bui), thermal power plants powered by crude oil, natural gas, and diesel, solar power, and imports from La Cote d'Ivoire. Until the early 2000s, large hydroelectric dams dominated Ghana's electricity generation. Due to the unreliable weather patterns, Ghana increased its reliance on thermal power. Thermal power contributes the highest percentage in terms of electricity generation in Ghana and is predominantly supplied by Independent Power Producers (IPPs). Ghana's electricity industry operates the corporate utility model as its business model. This model is typically 'vertically integrated', with a single corporation selling the majority of power generated by its generation assets to its retail business, which then sells the electricity to retail market consumers. The corporate utility model has a straightforward value proposition that is based on increasing the number of energy units sold. The unit volume business model drives the entire energy value chain to increase throughput, locking system users into unsustainable practices. This report uses the qualitative research approach to explore the electricity industry in Ghana. There is the need for increasing renewable energy such as wind and solar in the electricity generation. The research recommends two critical business models for the penetration of renewable energy in Ghana's power sector. The first model is the peer-to-peer electricity trading model which relies on a software platform to connect consumers and generators in order for them to trade energy directly with one another. The second model is about encouraging local energy generation, incentivizing optimal time-of-use behaviour, and allow any financial gains to be shared among the community members.

***Keywords*—**Business model innovation, electricity generation, renewable energy, solar energy, sustainability, wind energy.

## I. Introduction

CARBON dioxide ($CO_2$) emissions have been steadily going up; likewise, the level of atmospheric CO2 has increased [1]. Today, the energy sector accounts for roughly three quarters of greenhouse gas emissions, with fossil fuels accounting for the majority of greenhouse gas emissions [2]. According to the Intergovernmental Panel on Climate Change, human-caused greenhouse gas emissions are primarily responsible for approximately 1.1 °C of warming since 1850-1900 [3]. Under current trends, the average global temperature is expected to rise up to and beyond 1.5 °C – the Paris Agreement's target – over the next 20 years, and limiting the warming to within 1.5-2 °C will be impossible unless immediate and significant reductions in greenhouse gas emissions occur. Ghana relies heavily on petroleum, biomass and hydropower as its primary energy supply [4]. Ghana's electricity generation was dominated by large electricity dams until the early 2000s [5], [6]. However, thermal generation has recently increased from 1,159 GWh in 2005 to 5,644 GWh in 2015 [6]. In Ghana, thermal energy sources for electricity generation include light crude oil, natural gas, and diesel [6]. Because of the high proportion of thermal sources, $CO_2$ emissions into the atmosphere are higher. Because energy systems contribute to greenhouse gas emissions [7], there is a call for a complete transformation in how we produce, transport, and consume energy [2]. Renewable energy technologies are becoming increasingly affordable, giving electricity an advantage in the race to net zero. To enable the penetration of renewable energy into Ghana's power sector, changes in the business model are required.

The main goal of this paper is to propose sustainable business model innovation in the Ghana power sector in order to reduce reliance on fossil fuels in electricity generation by increasing renewable energy, thereby reducing greenhouse gas emissions and averting climate change. The path to net-zero emissions is narrow, and staying on it necessitates the rapid and widespread deployment of all available clean and efficient energy technologies [2]. The literature review will concentrate on sustainability and business model innovation in order to better understand the research.

## II. Literature Review

As the world transitions to a low-carbon economy, technological, economic, and societal advancements necessitate changes in business models [8]. A disruptive innovation is defined as the introduction of a better business model into an existing market. "A business model describes the rationale of how an organization creates, delivers, and captures value," according to [9]. A business model, as suggested, describes the benefit an enterprise will provide to customers, how it will do so, and how it will capture a portion of the value it provides [10], [11]. Designing business models requires determining how to deliver benefits and capture value [10], [12]. Reference [9] believes that the best way to describe a business model is through nine basic building blocks that demonstrate the logic of

Victor Birikorang Danquah holds an M.B.A. in Energy Management from the University of Aberdeen, United Kingdom (e-mail: captainbiko@yahoo.com).

how a company intends to make money. Business model innovation is frequently classified as technological, organizational, or strategically driven [12]. These categories are used to refine eight generic sustainability value propositions [13]. Sustainability entails developing strategies to ensure that the entity only uses resources at a rate that allows them to be replenished, ensuring that they will continue to be available, while also limiting waste emissions to levels that do not exceed the environment's capacity to absorb them [14]. Sustainable development is concerned with the environmental, social and economic consequences, also known as the triple bottom line [15]. The concept emphasizes the importance of organizations meeting the needs of people (social goals), the environment (environmental goals), and profits (economic goals). Addressing inequalities is critical to achieving long-term development [16]. Sustainable Business Models (SBMs) have recently been discussed as a means of balancing ecological, social, and economic needs through value proposition, stakeholder involvement, and taking responsibility for environmental burdens rather than transferring them to customers or suppliers [12]. The deployment of specific technologies in the energy value chain, such as storage [17], [18], solar generation [19], and electric vehicle charging [20], has been the focus of business model innovation research in the energy field. These are important contributions to our understanding of how new technologies allow new entrants to compete with incumbent firms. Other research investigates the iterative nature of technology selection and business model design, as well as the interdependence of revenue capture methods and business model design [21], [22]. These contributions also demonstrate the importance of business model research to the energy policy community by examining how business model innovations can have both productive and disruptive effects across energy markets [23], [24]. The potential for SBM innovation in Ghana's power sector, on the other hand, is less well understood.

The six SDG Transformations (see Fig. 1) provide a detailed framework on which to construct integrated strategies for the SDGs [25]. It is recognized that all 17 SDGs can be achieved through six major societal transformations focused on: (1) education and skills, (2) health and well-being, (3) clean energy and industry, (4) sustainable land use, (5) sustainable cities, and (6) digital technologies [26]. The six transformations lay out a plan of action for government agencies, businesses, and civil society. Transformation (3) seeks to ensure universal access to modern energy sources, to decarbonize the energy system by the mid-century mark in accordance with the Paris Agreement, and to reduce industrial pollution of soil, water, and air. Technology (6) permits artificial intelligence to cause disruption in almost every industry [25]. This includes precision agriculture in the agricultural sector, autonomous vehicles in the mining sector, robotics in the manufacturing sector, e-commerce in the retail sector, e-payments, trading strategies in the finance sector, social work in media, diagnostics and telemedicine in health, online learning in education, e-governance, e-voting in government, and science and technology [25]. Digital technologies have the potential to increase productivity, lower production costs, reduce emissions, broaden access, dematerialize production, improve market matching, enable the use of big data, and make public services more accessible. They can also help to improve resource efficiency, promote the circular economy, enable zero-carbon energy systems, monitor and protect ecosystems, and play other critical roles in achieving the SDGs.

SBM Innovation in the power sector requires the use of digital technologies to disrupt the current business model to ensure universal access to modern energy sources such as renewable energy.

## III. Methodology

A qualitative approach was deemed most appropriate for this descriptive and exploratory study of SBM innovation in Ghana's power sector [27]. The secondary data obtained from a review of previous literature, The Energy Commission of Ghana, the International Renewable Energy Agency (IRENA), and the Oxford Institute of Energy Studies were used in this research. There is also a Renewable Energy Master-Plan (REMP) with the vision of transforming Ghana into a country with expertise in renewable energy research, production, and services.'

## IV. Findings

Ghana's primary energy supply is dominated by petroleum, biomass, and hydroelectricity. Oil accounted for 44.48% of primary energy supply in 2015, followed by biomass (37.87%), hydroelectricity (5.27%), and natural gas (12.38%) [28]. Petroleum products and biomass dominate the final energy consumed in Ghana. In 2015, petroleum products such as gasoline, diesel, LPG, and jet fuel accounted for 47% of total energy consumed [28]. 40% of the energy came from biomass in the form of firewood, charcoal, and agricultural waste. Only 13% was accounted for by electricity [7]. The Ministry of Energy is in charge of establishing Ghana's national electricity policy. Ghana's state-owned Volta River Authority (VRA) is in charge of producing and distributing electricity. Ghana's largest power plant is the VRA-operated Akosombo hydroelectric facility. The Brong-Ahafo, Northern, Upper East, and Upper West Regions of northern Ghana are served by the Northern Electrification Department (NED), a VRA subsidiary [29].

The Electricity Company of Ghana (ECG), established in February 1997 under the company's code (1963), is a limited liability company that is wholly owned by the Government of Ghana and operates under the Ministry of Energy. On April 1, 1947, it was established as the Electricity Department, and in 1962, it was renamed the Electricity Division. It was later renamed Electricity Corporation of Ghana by NLC Decree 125 in 1967. The company's goals are to buy electricity in bulk from the VRA or any other supplier for distribution and sale to consumers in eight out of the 16 regions in Ghana [30].

Government policies (from the Ministry of Energy) heavily influence ECG's strategic direction [31]. The industry has been opened up to allow independent generators to generate energy and transmit it to customers; as a result, ECG now purchases from transmission companies rather than generators and distributes it to customers [31]. ECG does not set the rate that customers pay. The tariff set by the government determines it. The power sector has been deregulated in order to foster private-sector investment. The private sector is encouraged to diversify into thermal power and enter directly into power purchase agreements with bulk power end users such as mining companies [31].


Fig. 1 The Six SDG Transformations [25]

TABLE I
GHANA THERMAL POWER GENERATION FOR 2021 [34]

| Plant Description | Location | Fuel | Nameplate Cap (MW) | Dependable Cap (MW) | Generation 2020 (GWh) | Gas Consumed 2020 (MMBTU) |
|---|---|---|---|---|---|---|
| TAPCO (T1) | West | LCO/Gas | 330 | 300 | 1,087 | 9,074,910 |
| TICO (T2) | West | LCO/Gas | 340 | 320 | 1,193 | 10,564,047 |
| TT1PP | East | LCO/Gas | 110 | 100 | 427 | 5,310,005 |
| TT2PP | East | Gas | 80 | 70 | 90 | 869,884 |
| KTPP | East | Gas/Diesel | 220 | 200 | 368 | 3,915,969 |
| Ameri | West | Gas | 250 | 230 | 1,283 | 8,789,571 |
| CENIT | East | LCO/Gas | 110 | 100 | 711 | 8,099,758 |
| Sunon Asogli | East | Gas | 560 | 520 | 2,905 | 11,350,911 |
| Karpower | West | Gas/Diesel | 470 | 450 | 3,128 | 25,826,036 |
| AKSA | East | HFO/Gas | 370 | 330 | 398 | |
| Genser | East | Gas | 22 | 18 | 511 | 5,101,989 |
| Cenpower | East | LCO/Gas | 360 | 325 | 568 | 2,835,096 |
| Twin City | West | LCO/Gas | 203 | 202 | 196 | 1,676,366 |
| Bridge Power | East | LPG/Gas | 154 | 145 | | |
| Early Power | East | LCO/Gas | 144 | 140 | 10 | |
| | East | | 2,130 | 1948 | 5,988 | 37,483,611 |
| | West | | 1,593 | 1,502 | 6,888 | 55,930,930 |
| | Total | | 3,723 | 3,450 | 12,876 | 93,414,541 |

Large electricity dams dominated Ghana's electricity generation until 2003. However, thermal generation has recently increased significantly [32]. Ghana's power supply sources are from hydroelectricity 38%, thermal fuelled by crude oil, natural gas and diesel 61%, solar less than 1% and also imports from La Cote D'Ivoire. Electricity demand in Ghana has been steadily increasing at a rate of 7% per year over the last decade, and this trend is expected to continue for the next 5 years or so [33]

Thermal power plants represent some 70% of the dependable capacity [33]. Evidence suggests that in 2020, thermal plants generated some 63% of total electricity production [33]. Total electricity generation in 2020 was slightly less than 20,000 GWh; this is expected to rise to 21,265 GWh in 2021 and 28,550 GWh by 2026 [34]. The 2021 Electricity Supply Plan includes some additional small hydroelectricity and solar electricity generation, but gas-fired power will account for nearly all of the current committed increase in generation. The thermal power generation for 2021 is shown in Table I.

Because Bridge Power and Early Power were not operational in 2020, the East (Tema) enclave had 52% of dependable capacity but only 46% of actual generation. Because some plants used alternative fuels for part of the year, the percentage of gas consumed was lower [33].

Total installed renewable energy capacity (electricity) was approximately 1,602 MW at the end of 2015, accounting for approximately 43.8% of total national installed electricity, with hydropower accounting for 43.2%. Due to low rainfall in the Volta basin, hydropower generation decreased significantly between 2007 and 2015 [5]. According to data from the International Renewable Energy Agency [35], renewable energy accounted for 31.3% of total electricity capacity in 2020. Table II depicts renewable energy capacity from 2011 to 2020.

TABLE II
RENEWABLE ENERGY CAPACITY FOR GHANA 2011-2020 [35]

| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total Renewable Energy | | | | | | | | | | |
| MW | 1,187 | 1,187 | 1,590 | 1,593 | 1,623 | 1,626 | 1,631 | 1,656 | 1,656 | 1,663 |
| Hydropower | | | | | | | | | | |
| MW | 1,180 | 1,180 | 1,580 | 1,580 | 1,584 | 1,584 | 1,584 | 1,584 | 1,584 | 1,584 |
| Wind Energy | | | | | | | | | | |
| MW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Solar Energy | | | | | | | | | | |
| MW | 0 | 0 | 3 | 5 | 30 | 34 | 39 | 105 | 106 | 106 |
| Solar Energy (Photovoltaic) | | | | | | | | | | |
| MW | 7 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Off-Grid Capacity | | | | | | | | | | |
| Total Renewable Energy | | | | | | | | | | |
| MW | 6.774 | 6.774 | 6.774 | 9.624 | 13.914 | 15.152 | 15.888 | 15.892 | 16.292 | 16.292 |
| Solar Photovoltaic | | | | | | | | | | |
| MW | | | | 1.350 | 5.609 | 6.847 | 7.583 | 7.587 | 7.987 | 7.987 |
| Other Renewable Energy | | | | | | | | | | |
| MW | 6.774 | 6.774 | 6.774 | 8.274 | 8.305 | 8.305 | 8.305 | 8.305 | 8.305. | 8.305 |
| Renewable Energy Share of Electricity Capacity | | | | | | | | | | |
| % | 54.5 | 51.9 | 51.6 | 56.1 | 44.1 | 42.6 | 36.8 | 37.1 | 31.3 | 31.3 |

42.5% of the $CO_2$ emissions in the world come from the production of electricity [36]. Further, 73% of this can be attributed to coal-fired power plants, which produce electricity while emitting 950 grammes of $CO_2$ per kilowatt-hour as opposed to 350 grammes for gas-fired power plants. Renewable energy-based power plants, such as those powered by hydro, wind, solar PV, and solar thermal, only produce $CO_2$ during construction [36]. Accordingly, a solar PV system "emits" between 60 and 150 grammes of $CO_2$ (depending on where the solar panels were manufactured), a wind turbine between 3 and 22 grammes, and a hydropower plant 4 grammes for every kilowatt-hour of electricity produced. Table III gives $CO_2$ emissions for electricity production by fuel type.

TABLE III
$CO_2$ EMISSIONS FOR ELECTRICITY PRODUCTION [37]

| Generation Type | Tons $CO_2$ per MWh |
|---|---|
| Nuclear | 0 |
| Hydro power | 0 |
| Coal | 0.999 |
| Oil | 0.942 |
| Gas | 0.439 |
| Geothermal, Solar, Tide, Wave, Ocean, wind, Waste and other | 0 |

According to data from the World Bank, $CO_2$ emissions from electricity and heat production, total (% of total fuel combustion) between 1971 to 1997 averaged 4.372818519% [38]. $CO_2$ emissions however jumped to 22.5274725% in 1998 when thermal sources were added to the generation. Fig. 2 shows the percentage of $CO_2$ emissions from electricity production in Ghana between 1971 and 2014. It can be seen that between 1971 and 1997 when Ghana relied solely hydropower for electricity generation $CO_2$ emissions remained low virtually negligible in 1997. However, upon the decision by government to introduce thermal sources into the generation mix, emissions remained high rising to about 31% in 2007.

Electricity and heat production saw the largest jump in $CO_2$ emissions by industry in 2021, increasing by more than 900 Mt. [39]. Renewable energy sources produce electricity that has a much smaller environmental impact and is practically endless [36]. Renewable power generation technologies, such as floating offshore wind and emerging ocean energy technologies, could support long-term development and drive a vibrant blue economy [40]

## V. DISCUSSION

Every industry is built on long-held, often implicit, assumptions about how to make money [41] These guiding beliefs reflect widely held beliefs about customer preferences, the role of technology, regulation, cost drivers, and the foundation of competition and differentiation.

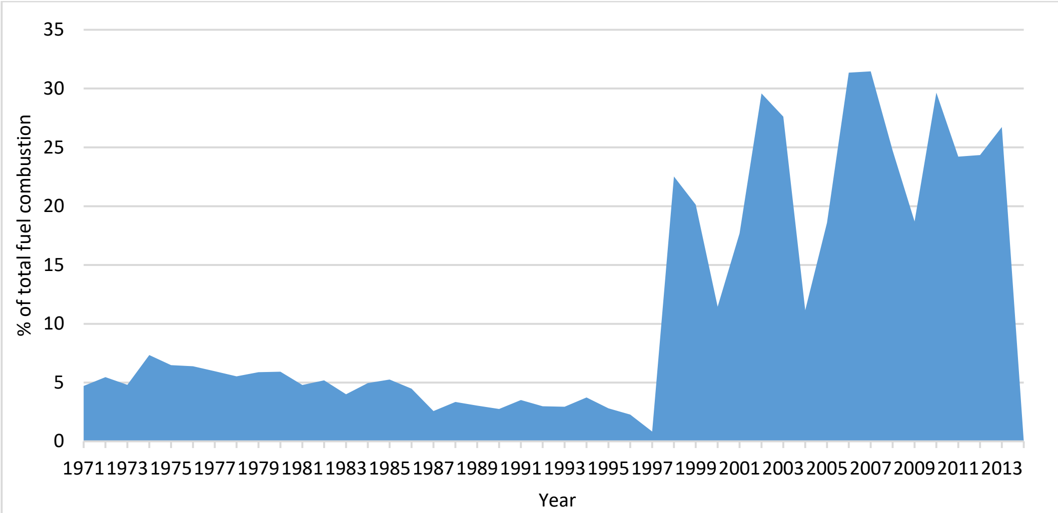


Fig. 2 $CO_2$ emissions from electricity and heat production, total (% of total fuel combustion) in Ghana [38]

The corporate utility business model has traditionally been the dominant business model in Ghana's power sector [42]. The corporate utility model operates a vertically integrated business strategy where a large single corporation sells the majority of the power it generates to its retail business for onward sale to the retail consumer market. The value proposition is based on the capacity to increase the number of energy units it can sell and this is what actually drives the entire value chain the effect of which locks system users into practices which are unsustainable [43]. The unit volume business model forces the entire energy value chain's throughput to expand, tying system users to harmful behaviours. [44]-[46]. Because business revenues were typically tied directly to the sale of more units of energy, the route to market for services that can reduce final demand for grid electricity, such as energy efficiency and demand-side management, was also limited.

Because of the inherent variability of weather-dependent renewables, the entire system faces challenges, necessitating the presence of other technologies that can provide system flexibility in order to provide a reliable electricity supply. According to the findings, due to the country's unreliable rainfall patterns, hydropower generation has remained low, with an increased reliance on thermal power. Our reliance on fossil fuels has been the primary cause of environmental damage thus far, and ongoing damage from this use can be avoided if we shift to renewable energy sources such as wind, solar, and hydropower.

Using renewable energy instead of fossil fuels to generate electricity has significant health benefits. Air and water pollution caused by fossil-fuel power plants has been linked to respiratory issues, neurological damage, heart attacks, and cancer [47]. It has been discovered that replacing fossil fuels with renewable energy reduces premature mortality and lost workdays, as well as overall health costs [47]. Ghana, like many other countries, is focusing on incorporating renewable energy into the national energy mix to ensure energy security, a cleaner environment, and to help mitigate climate change [5].

Ghana has signed several international conventions, treaties, and regional programmes aimed at promoting sustainable energy development, including the UN Sustainable Energy for All (SEforALL) Initiative, the Sustainable Development Goals (SDGs), the Paris Agreement on Intended Nationally Determined Contributions (INDCs), the African Union Agenda 2063, the Economic Community of West African States (ECOWAS) White Paper on Energy Access, and the ECOWAS Renewable Energy Efficiency Policies [5]. All of these conventions, treaties, and regional programmes aim to vigorously promote renewable energy and, as a result, reduce the incidence and effects of climate change, in order to ensure a future conducive to its generation [5]. Renewable power generation technologies, dominated by wind and solar, have developed rapidly over the last decade, according to the 2017 version of the Renewable Global Futures Report [48].

Wind energy is non-polluting and emits no carbon dioxide as a by-product [49]. It is also entirely renewable because there is always wind. Prices for energy sources such as fossil fuels frequently fluctuate [6]. A typical wind farm's carbon footprint is repaid in six months or less, providing decades of zero-emission energy that replaces fossil fuel energy [50]. Solar energy is completely renewable, and the installation costs can be recouped through energy bill savings [49]. The only disadvantage of solar panels is that they deteriorate over time and are not completely weather-proof in countries with erratic weather patterns. Renewables are becoming the default option for new generation capacity.

The need for greater penetration of renewable energy into Ghana's power sector has resulted in the emergence of new business models that are fundamentally different from the corporate utility model.

In January 2016, a mini-grid policy was approved to mainstream mini-grid electrification into the National Electrification Scheme [5]. Mini-grids are public-sector investments under the policy, with the VRA and the ECG/ NEDCo responsible for generation and distribution, respectively. Under the rural electrification arrangement, customers on mini-grids would have the same policy as those on the main electricity grid [5].

With changes in the location of financial value, vertically integrated corporate utilities can choose to remain vertically integrated or evolve in various directions, such as owning and aggregating distributed assets (e.g. distributed storage, metres, electric vehicle charging points), constructing large-scale low-carbon power plants (e.g., offshore wind, nuclear), or providing connected services for assets owned by others (e.g. demand side response) [40].

Systemic innovations are needed that go beyond enabling technologies to integrate innovations in business models, markets and regulations, and system operations to unlock the flexibility of the power system and integrate rising shares of Renewable Energy.

The International Renewable Energy Agency identified 30 innovations for integrating wind and solar PV in power systems, which are clustered in four dimensions as shown in Fig. 3 [40]. To form an innovative solution, innovations from two or more dimensions must be combined. Because there is no "one-size-fits-all" solution, these must be tailored to each country's specific power system characteristics.

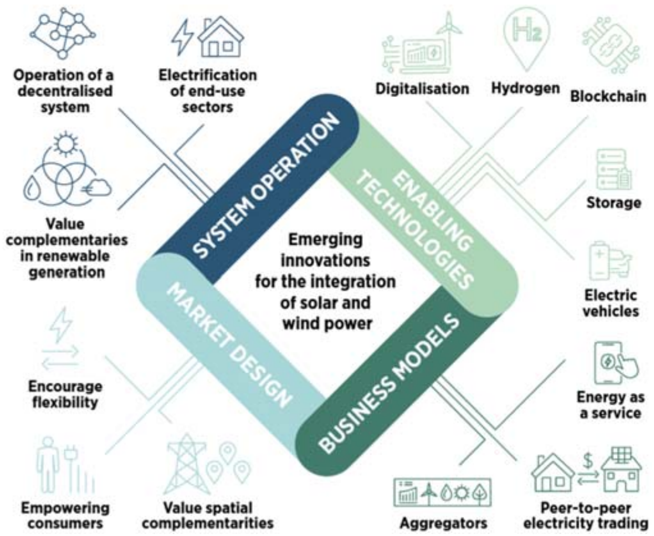


Fig. 3 Emerging technologies for integrating variable renewable energy sources. Technologies for enabling, market design, business models, and system operation [40]

Policies based on sustainability seek to achieve equity in resource distribution, preserve the integrity of the global ecosystem, and increase human population self-reliance [23]. The Sustainable Energy for All (SEforALL) [5] initiative aims to mobilise the UN system, governments, the private sector, and civil society to take concrete action toward three critical goals that must be met by 2030: The goals are:

- Ensuring that everyone has access to modern energy services,
- Doubling the rate at which energy efficiency is improving globally, and
- Increasing the proportion of renewable energy sources in the world's energy mix [5].

In 2012, the Ghana SEforALL Action Plan sought to address three key areas [5].

- Off-grid renewable energy-powered power solutions for remote communities
- Access to modern cooking energy; and
- Productive use of energy

## VI. Conclusion

As the world transitions to a low-carbon economy, technological, economic, and societal advancements necessitate changes in business models. A business model explains how an organisation creates, delivers, and captures value. The traditional electricity business model has a relatively simple value proposition; to remain profitable, national utilities rely on increasing kWh units sold (relative to costs) [51], [52], [42]. Both the national focus and the reliance on increasing unit sales have an impact on new entrants' ability to compete in or enter the market [38]. The entire energy value chain is driven by the unit volume commercial model to improve throughput, trapping system users into unsustainable practices [44]-[46]. Because of the inherent variability of weather-dependent renewables, the entire system faces challenges, necessitating the presence of other technologies that can provide system flexibility in order to provide a reliable electricity supply. Renewables are becoming the default option for new generation capacity. Even though Ghana's energy mix is currently clean, with hydropower accounting for 43.2% of installed capacity in 2015, it is prudent that Ghana begins to develop its renewable energy resources in order to keep it clean, reduce reliance on imported fuels for power generation, and contribute power to the country's energy needs for accelerated economic development [5]. A thriving renewable energy sector will also generate 'homegrown' jobs. Indeed, recent renewable energy programmes and projects have demonstrated that renewable energy interventions have enormous potential to reduce poverty and improve the country's socioeconomic development, particularly in rural communities. In light of this, efforts have been made to develop a clear regulatory framework for the Renewable Energy sector, including the development of policies, strategy documents, and the enactment of laws. However, policymakers should pay close attention to emerging business models in the electricity supply market because they have the potential to result in significant benefits, both in terms of system efficiency and socioeconomic gains. Future policy can be guided by the identification and classification of value propositions, value capture, and business model archetypes.

## VII. Recommendations

Two crucial business models are suggested in this paper for the use of renewable energy in Ghana's power sector. Peer-to-peer (P2P) electricity trading is the first business model. In this arrangement, consumers and generators are linked via a software platform to enable direct energy trading between them.

Customers can select a generator based on price, energy type, or location, and they can switch generators as often as they want. This is an exchange that operates outside of the existing wholesale trading market. By increasing the visibility of nearby generators and community energy projects, the platform will aim to facilitate the development of local renewable energy markets. The P2P business model's success is dependent on consumers' willingness to change. The second business model involves empowering communities to operate and maintain a self-contained grid that supplies power to the entire community. With no connection to the mainland grid, the community's electricity can be supplied by renewable sources such as hydro, wind, and solar PV energy. This business model will encourage local energy generation, incentivize optimal time-of-use behaviour, and allow any financial gains to be shared among the community members. In the absence of clear commercial benefits, such models may be difficult to replicate in areas with existing grid access because they necessitate the participation of the entire community to reach an investable scale.

## References

[1] World Bank (2018). Atlas of Sustainable Development Goals 2018: World Development Indicators. Washington, DC: World Bank. doi: 10.1596/978-1-4648-1250-7. License: Creative Commons Attribution CC BY 3.0 IGO.
[2] IEA (International Energy Agency) (2021) Net Zero by 2050 A Roadmap for the Global Energy Sector, https://www.iea.org Net Zero by 2050 Interactive iea.li/nzeroadmap Net Zero by 2050 Data iea.li/nzedat
[3] Government of Ghana (2003). Draft National Renewable Energy Strategy. Unpublished
[4] IPCC (2021). Climate Change 2021. The Physical Science Basis. Contribution of Working Group 1 to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, UK.
[5] Energy Commission (2006). Strategic National Energy Plan 2006-2020. Available from http://energycom.gov.gh/files/snep/MAIN%20REPORT%20final%20PD.pdf
[6] Energy Commission (2019) Ghana Renewable Energy Master Plan.
[7] Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P. and Kriemann, B., (2014). IPCC 2014 Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
[8] Energy Institute (2020). Energy Insight: Future business models in electricity.
[9] Osterwalder, A., Pigneur, Y., (2010). Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers. John Wiley & Sons, United States
[10] Teece, D.J., (2010). Business models, business strategy and innovation. Long Range Plan. 43 (2), 172–194.
[11] Chesbrough, H., Rosenbloom, R.S., (2002). The role of the business model in capturing value from innovation: evidence from Xerox Corporation's technology spin-off companies. Ind. Corp. Change 11 (3), 529–555
[12] Boons, F., Lüdeke-Freund, F., (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. J. Clean. Prod. 45, 9–19
[13] Bocken, N.M.P., Short, S.W., Rana, P., Evans, S., (2014). A literature and practice review to develop sustainable business model archetypes. J. Clean. Prod. 65, 42–56.
[14] Schaltegger, S., Lűdeke-Freund, F., and Hansen, E.G. (2012) 'Business cases for sustainability: the role of business model innovation for corporate sustainability', Int. J. Innovation and Sustainability Development. Vol. 6, No.2 pp.95-129
[15] Elkington, J. (2004) 'Enter the triple bottom line' in Henriques, A. and Richardson, J. (Eds): The Triple Bottom Line, Does It All Add Up?, pp 1-16, Earthscan Publications, London
[16] Gaigbe-Togbe, V. (2015). The impact of socio-economic inequalities on early childhood survival. Results from the Demographic and Health Surveys. Population Division Technical Paper 2015/1. New York: United Nations.
[17] He, X., Delarue, E., D'haeseleer, W., Glachant, J.M., (2011). A novel business model for aggregating the values of electricity storage. Energy Policy 39 (3), 1575–1585.
[18] Taylor, P.G., Bolton, R., Stone, D., Upham, P., (2013). Developing pathways for energy storage in the UK using a coevolutionary framework. Energy Policy 63, 230–243
[19] Huijben, J.C.C.M., Verbong, G.P.J., (2013). Breakthrough without subsidies? PV business model experiments in the Netherlands. Energy Policy 56, 362–370.
[20] San Román, T.G., Momber, I., Abbad, M.R., Miralles, Á.S., (2011). Regulatory framework and business models for charging plug-in electric vehicles: infrastructure, agents, and commercial relationships. Energy Policy 39 (10), 6360–6375
[21] Kley, F., Lerch, C., Dallinger, D., (2011). New business models for electric cars—A holistic approach. Energy Policy 39 (6), 3392–3403.
[22] Okkonen, L., Suhonen, N., (2010). Business models of heat entrepreneurship in Finland. Energy Policy 38 (7), 3443–3452
[23] Channell, J., Jansen, H.R., Syme, A.R., Savvantidou, S., Morse, E.L., Yuen, A., (2013). Energy Darwinism: The Evolution of the Energy Industry. Citi Research, New York, NY.
[24] Richter, M., (2013). Business model innovation for sustainable energy: German utilities and renewable energy. Energy Policy 62, 1226–1237. http://dx.doi.org/ 10.1016/j.enpol.2013.05.038
[25] Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., and Rockström, J. (2019). Six Transformations to achieve the Sustainable Development Goals. Nature Sustainability, 2(9), 805–814. https://doi. org/10.1038/s41893-019-0352-9.
[26] Sachs, J., Kroll, C., Lafortune, G., Fuller, G., Woelm, F. (2021). The Decade of Action for the Sustainable Development Goals: Sustainable Development Report 2021. Cambridge: Cambridge University Press.
[27] Eisenhardt, K.M. (1989), "Building theories from case study research", Academy of Management Review, Vol. 14 No. 4, pp. 532-50.
[28] Energy Commission, (2016). National Energy Statistics 2006-2015. The Ghana Energy Commission.
[29] https://www.esi-africa.com/top-stories/ghana-s-electricity-industry/
[30] https://www.ghana.gov.gh/mdas/ebd9b3ac96/
[31] https://www.ide.go.jp/English/Data/Africa_file/Company/ghana02.html
[32] Ministry of Energy, 2021. https://www.energymin.gov.gh/
[33] Fulwood, M., (2021). Does Ghana need LNG? July 2021 The Oxford Institute for Energy Studies. OIES Energy Comment
[34] Ghana (2021) Electricity Supply Plan, Ghana Energy Commission
[35] IRENA (2021), Renewable capacity statistics 2021 International Renewable Energy Agency (IRENA), Abu Dhabi
[36] https://www.planete-energies.com/en/medias/close/electricity-generation-and-related-co2-emissions
[37] Cited in B. Gaiddon, M. Jedliczka, *Environmental Benefits of PV Systems in OECD Cities*, September 2006.
[38] https://data.worldbank.org/indicator/EN.CO2.ETOT.ZS
[39] https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2
[40] IRENA (2021), World Energy Transitions Outlook: 1.5°C Pathway, International Renewable Energy Agency, Abu Dhabi. Available for download: www.irena.org/publications
[41] Jong, M., and Dijk M. (2015), Disrupting beliefs: A new approach to business-model innovation McKinsey & Company.
[42] Hannon, M.J., Foxon, T.J., Gale, W.F., [(2013). The co-evolutionary relationship between energy service companies and the UK energy system: implications for a lowcarbon transition. Energy Policy 61, 1031–1045.
[43] Hall, S., Roelich, K., (2015). Local Electricity Supply: Opportunities, archetypes and outcomes. Ibuild/RTP Independent Report. March 2015, Available online at: ⟨https://research.ncl.ac.uk/ibuild/outputs/local_electricity_supply_report_WEB. pdf⟩.
[44] Unruh, G.C., (2002). Escaping carbon lock-in. Energy policy 30 (4), 317–325. Walker, G., Hunter, S., Devine-Wright, P., Evans, B., Fay, H., 2007. Harnessing community energies: explaining and evaluating community-based localism in renewable energy policy in the UK. Global Environ. Politics 7 (2), 64–82.
[45] Apajalahti, E.L., Lovio, R., Heiskanen, E., (2015). From demand side management (DSM) to energy efficiency services: A Finnish case study.

Energy Policy 81, 76–85.

[46] Roelich, K., Knoeri, C., Steinberger, J.K., Varga, L., Blythe, P.T., Butler, D., Purnell, P., (2015). Towards resource-efficient and service-oriented integrated infrastructure operation. Technol. Forecast. Soc. Change 92, 40–52

[47] Machol, R (2013). Economic Value of U.S. fossil fuel electricity health impacts. Environment International 52 75-80

[48] REN21 (2017). Renewables Global Futures Report. Great debates towards 100% renewable energy. Paris: REN21 Secretariat.

[49] https://www.energy.gov/eere/wind/advantages-and-challenges-wind-energy

[50] https://www.aweblog.org/the- truth- about- power/

[51] Blyth, W., Gross, R., Speirs, J., Sorrell, S., Nicholls, J., Dorgan, A., Hughes, N., (2014). Low Carbon Jobs: The Evidence for Net Job Creation from Policy Support for Energy Efficiency and Renewable Energy, UKERC, Available at, ⟨http://www.ukerc.ac.uk/publications/low-carbon-jobs-the-evidence-for-net-job-creation-from-policysupport-for-energy-efficiency-and-renewable-energy.html⟩.

[52] Blyth, W., McCarthy, R., Gross R. (2014). Financing the Power Sector: is the money available? United Kingdom Energy Research Centre Working Paper. Available online at ⟨www.ukerc.ac.uk/support/tiki-download_file.php?fileId¼3628⟩, (accessed May 2014)