

Review

Climate Change and Variability in Ghana: Stocktaking

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Abstract: This paper provides a holistic literature review of climate change and variability in Ghana by examining the impact and projections of climate change and variability in various sectors (agricultural, health and energy) and its implication on ecology, land use, poverty and welfare. The findings suggest that there is a projected high temperature and low rainfall in the years 2020, 2050 and 2080, and desertification is estimated to be proceeding at a rate of 20,000 hectares per annum. Sea-surface temperatures will increase in Ghana's waters and this will have drastic effects on fishery. There will be a reduction in the suitability of weather within the current cocoa-growing areas in Ghana by 2050 and an increase evapotranspiration of the cocoa trees. Furthermore, rice and rooted crops (especially cassava) production are expected to be low. Hydropower generation is also at risk and there will be an increase in the incidence rate of measles, diarrheal cases, guinea worm infestation, malaria, cholera, cerebro-spinal meningitis and other water related diseases due to the current climate projections and variability. These negative impacts of climate change and variability worsens the plight of the poor, who are mostly women and children.

Keywords: climate change and variability; agriculture; energy; greenhouse gases; health; poverty; Ghana

1. Introduction

In recent times, climate change has gained great attention in global discussion. This concern about climate change is due to its adverse impact on the living conditions of mankind. Though when it comes to some developmental issues like poverty, discussions are normally skewed to developing countries like countries in Sub-Saharan Africa, Latin America and some countries in Asia; however, issues on climate change have taken the centre stage of developmental discussion globally. Increasingly, developing countries particularly countries in Africa are much concerned about climate change since they are more vulnerable. Climate change can be seen as a major threat to sustainable growth and development in Africa. As a result, the efforts of African countries to achieve the Millennium Development Goals may be seen as a mirage if the adverse effects of climate change are not addressed. Among the continents which are responsible for climate change, Africa is the least contributor; however, the continent is more vulnerable to the effects of climate change due to its overdependence on rain-fed agriculture, compounded by factors such as widespread poverty and weak capacity. The main long-term impacts of climate change include: changing rainfall patterns causing reduction in agriculture production and reducing food security, worsening water security, decreasing fish resources in large lakes due to rising temperature and shifting vector-borne diseases. Furthermore, rising sea level resulting from climate change affects low-lying coastal areas with large populations, leading to increased risk of conflict over scarce land and water resources. The adverse effect from climate change in the form of reduction of agricultural production ends up retarding the growth of countries in Africa, since a greater proportion of the national income of most African countries is from agriculture. In addition, the agriculture sector serves as the source of livelihood (that is, source of employment) for most people in Africa.

In an attempt to solve the problem of climate change, Ghana signed the United Nations Framework Convention on Climate Change (UNFCCC) at the Rio de Janeiro Earth Summit in June 1992, after the Convention was adopted on 9 May 1992 [1]. Three major physical impacts of climate change have been identified in Ghana and these are; temperature change, change in rainfall and sea level rise [2]. Owusu *et al.* [3] report that there is a shift in the rainfall regime in Ghana towards a longer dry season and vanishing wet season. In spite of the signing of the convention by Ghana, the country still faces the adverse effect of climate change in the form of health problems, climate induced disruption of agricultural systems, flooding of coastal areas which are already undergoing erosion and low operating water level of the only hydro-generating dam in the country, (which produces 80% of national electricity supply), as a result of reduced levels of precipitation [4]. These adverse effects of climate change facing the Ghanaian economy are due to the lack of capacity to undertake adaptive measures to address environmental problems and socio-economic costs of climate change.

Climate change introduces numerous uncertainties over the livelihoods of farming communities that depend heavily on the weather and climate ([5,6]). According to [7], climate change negatively affects the basic elements of food production such as soil, water and biodiversity. The World Bank [2] noted that, women are more susceptible to the impacts of climate change as a result of a combination of a number of factors including gender-based cultural norms, inheritance structures and household responsibilities. Due to the reliance of the Ghanaian economy on sectors (such as agriculture, energy and forestry) that are highly sensitive to climate change and its variability, it is necessary to review past studies of climate change and variability in Ghana. Specifically, this paper provides a literature review by;

- ✓ Examining climate change variability and projection in agriculture production.
- ✓ Assessing climate change variability and projection in the Energy sector.
- ✓ Analysing climate change variability and projection on human health.
- ✓ Discussing how climate change impacts Poverty, Gender and Welfare.

2. Historical Review of the Trend of Climate Change in Ghana

Ghana is located in West Africa and it is bordered in the north by Burkina Faso, east by Togo, west by Cote d'Ivoire and south by the Gulf of Guinea. It lies between latitudes 4.50°N and 11.50°N and longitude 3.50°W and 1.30°E. The country has a total land area of 239,460 km² and a water area of 8520 km². The country had a population size of about 24 million as at 2010 with an annual growth rate of about 2.5% [8]. This population is dominated by the youth. The main exports are cocoa, gold, timber, diamonds, bauxite, manganese, and hydropower. Until recently, the country has also started the exportation of crude oil. In 1991/1992 the poverty level in Ghana was about 51.7%, this has decreased consistently over the years to 39.5% in 1998/1999 and further to 28.5% in 2005/06 and 24.2% in 2012/13. The country has a high temperature with the average annual temperature ranging between 24 °C to 30 °C. In spite of this average annual temperature, there are instances where the temperature can be 18 °C and 40 °C in the southern and northern parts of Ghana, respectively. Rainfall in Ghana generally decreases from south to north. The wettest area in Ghana is the extreme southwest where annual rainfall is about 2000 mm. However, the annual rainfall in extreme north of Ghana is less than 1100 mm. The country has two main rainfall regimes which are the double maxima regime and the single maximum regime. In relation to the double maxima regime, the two maximum periods are from April to July and from September to November in Southern Ghana. While the single maximum regime is from May to October in Northern Ghana, this is followed by a long dry season from November to May. Over the years, the temperatures in all the ecological zones of Ghana are rising while rainfall levels have been generally reducing and patterns increasing becoming erratic [1].

Green House Gases

In the year 2000, the total direct greenhouse gas emission in Ghana was estimated at 12.2 MtCO₂e (based on carbon dioxide, methane, nitrous oxide and perfluorocarbons). This figure is about 173% above 1990 levels of -16.8 MtCO₂e and 96% lower than 2006 levels of about 23.9 MtCO₂e. The overall greenhouse gases emission increase by 107% from 1990 to 2006. The trend in greenhouse gases emissions has the potential of rising further as the economy continues to grow and expand its development frontier, based on the Kuznet hypothesis. The components of greenhouse gases for the years 2000 and 2006 are presented in Figure 1. For the year 2000, methane was the greatest component of greenhouse gases (constituting about 46%), followed by nitrous oxide (34%) and carbon dioxide (19%). The estimated emissions for methane, nitrous oxide, and carbon dioxide for the year 2000 are 6.2 MtCO₂e, 4.5 MtCO₂e and 2.6 MtCO₂e respectively. However, in the year 2006 carbon dioxide took over as the dominant component of greenhouse gases with a percentage of about 46. This was followed by Methane (34%) and Nitrous oxide (20%).

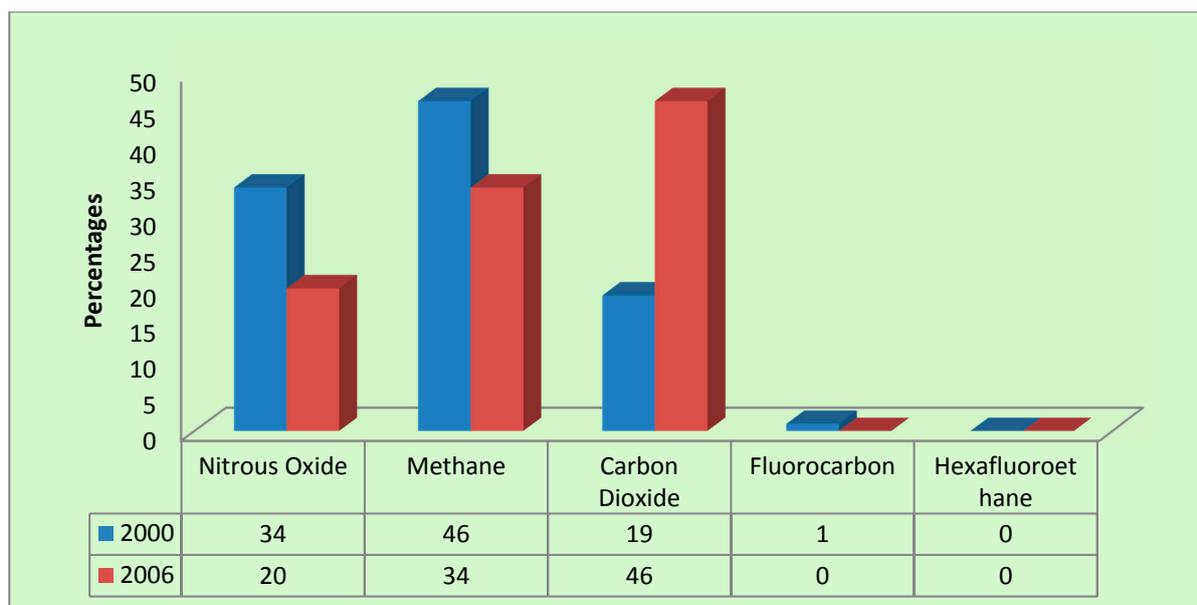


Figure 1. Components of Greenhouse Gases. Source: Author's compilation from [1].

In the year 2000, the largest of carbon dioxide contribution was from the energy sector with a rate of 55% (see Table A1). Over the years, carbon dioxide emission has increased due to the increase in forest and grassland conversion rate, an increase in fuel consumption for electricity production from thermal source as well as an increase in fuel consumption for transport. Though the industrial processing sector in 2000 contributed only 14% of carbon dioxide emission, the growth in the sector's contribution has been on the ascendancy. The agricultural sector dominates in the contribution of methane emissions, followed by waste sector, LUCF and energy in that order (see Table A1). Over the years, emission of methane has been increasing and this is attributed to the increase in enteric fermentation from the growing numbers of domestic livestock, rising disposal of waste on deep landfills as well as an increase in biomass consumption in the residential and on-site burning of biomass. These factors explain why the agricultural and waste sectors contribute more to the emission of methane. Similarly, the agricultural sector accounts for about 64% of the total nitrous oxide in 2000, followed by LUCF which accounts for 30% (see Table A1). The increasing trend of nitrous oxide over the years is attributed to the increase in the application of inorganic fertilizers and an increase in biomass consumption in the residential areas and on-site burning of biomass.

In relation to total emissions by sectors, the trend of emissions has been oscillating from the period 1990 to 2006. The energy sector had the lowest emission rate (that is, 19.5% of the total emissions, including LUCF) in 1990 with an estimated emission of 3265.58 GgCO_{2e}. However, the sector assumed the highest emission rate (that is about 48% of the total emissions) in the year 2000 with an estimated emission of about 5862.31 GgCO_{2e}. There was a decline in the proportion of emissions from the energy sector relative to the total emissions in 2003 and a slight increase in 2006. In spite of this, the growth in emissions in the energy sector has been increasing consistently (see Table A2). Emissions from industry processes have been reducing over the years as shown in Figure 2. This decrease in emission can be attributed to advancement in efficient technology which has the tendency of reducing the emissions of greenhouse gases. On the contrary, emissions from LUCF have increased over the years. Whereas in the year 1990, emission from the sector as a proportion of the total emissions was negative 150%, emissions

consistently increased hitting the height of about 35% in 2003 and declining in 2006 to 23.4%. This consistent increase in emission from the LUCF sector can be attributed to deforestation resulting from population growth and crude farming practices. The trend of emission in the agriculture sector is unstable from 1990 to 2006. In the year 2000, the agriculture sector experienced the highest emission rate as a proportion of the total emission reaching the height of about 44.9%. There was a sharp decline in emissions in 2003 and this increased slightly in 2006. The growth in emissions in the agriculture sector has been modest over the years (see Table A2). With the exception of the year 1990, proportional emission of greenhouse gases by the waste sector has been increasing from 2000 to 2006. This increase in emissions from the waste sector can be attributed to increase in population growth and poor waste management.

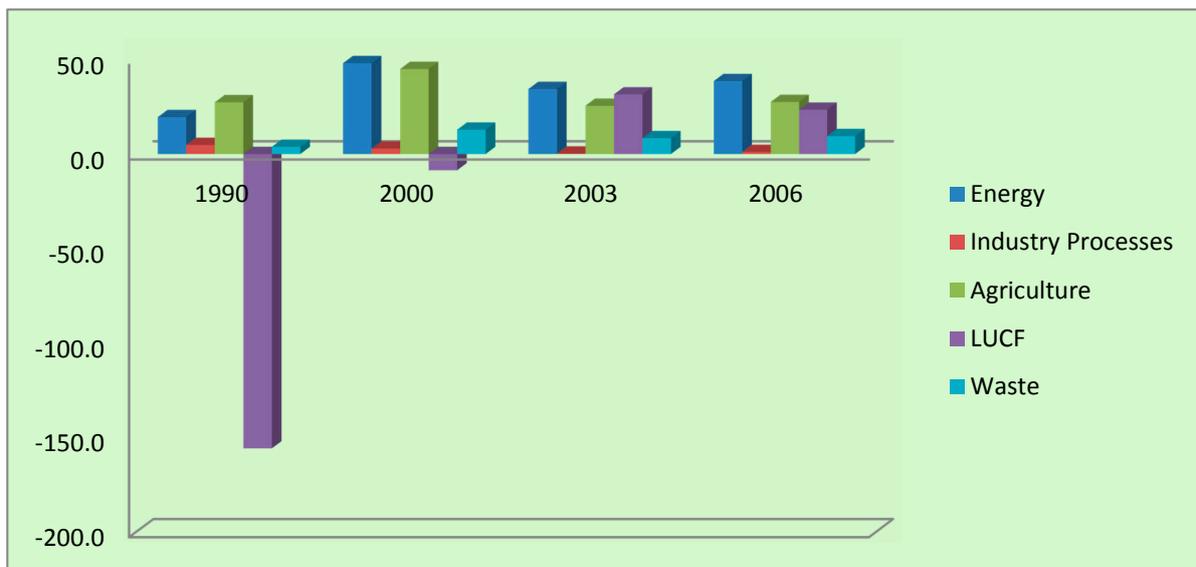


Figure 2. Sectoral Emissions of Greenhouse Gases. Source: Authors’ computation based on data from [1].

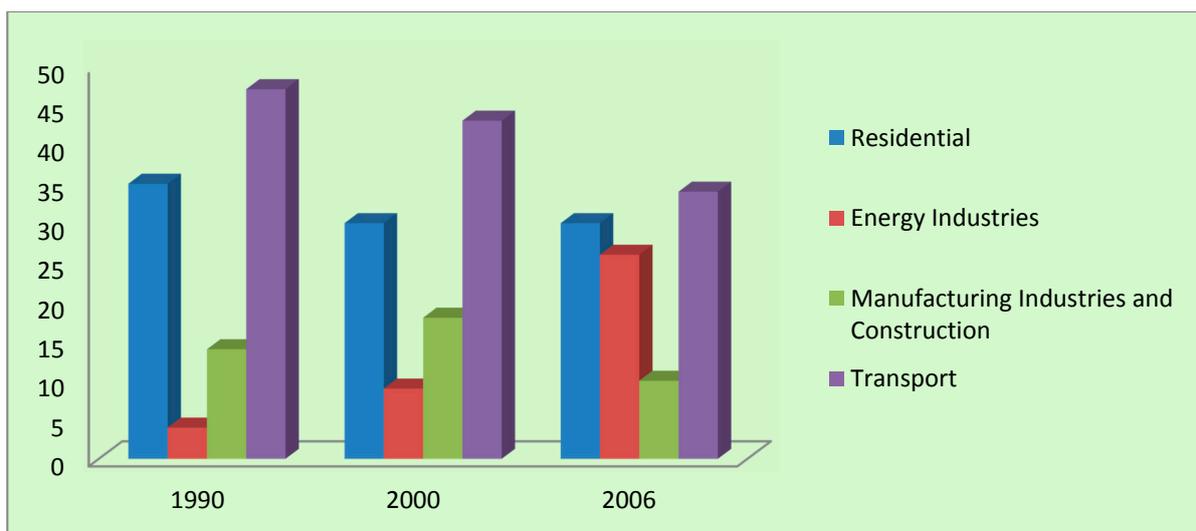


Figure 3. Constituent of Emissions in the Energy Sector. Source: Authors’ compilation from [1].

The constituent of the emissions by the energy sector is presented in Figure 3. Within the period under review, emissions from transportation dominated. In spite of the high emissions from transportation, the

trend has been declining consistently. Emission from residential is the second dominant contributor to the emissions from the energy sector. Though emissions from residents have been decreasing over the years, this decrease is not very significant as shown in Figure 3. Whereas the trend of emission from manufacturing industries and construction has been oscillating from the year 1990 to the year 2006, that of energy industries has been increasing consistently during the same period.

3. Literature Review

Climate change in the past two decades has become a topical issue at the global level. This is because the physical and biological systems on all continents are already being affected by recent changes in climatic conditions. There is overwhelming scientific evidence and consensus that climate change is largely human induced ([9,10]). Atmospheric concentration of carbon dioxide increased from a pre-industrial revolution value of 278 parts per million to 387 parts per million in 2008 [11]. Work by [12] reveals that since the industrial revolution, annual variations in the concentration of carbon dioxide have been occurring but the overall trend shows a rise in concentration. Greenhouse gas emissions have further increased over the last two decades. From 1.3% per annum in the 1990's, the rate of greenhouse emission increased to 3.3% per annum between 2000 and 2006 [13]. The occurrence of climate change is unambiguous. The IPCC estimates that there has been an average increase in temperature of 0.6 degrees Celsius over the past century. Atmospheric temperature has been unprecedented in the past 25 years with eleven out of the twelve warmest years occurring between 1995 and 2006 [14]. Countries are beginning to experience the consequences associated with global warming such as prolonged drought in the African Sahel and the widening of the transmission belt of malaria within tropical Africa [10]. Globally, the number of reported weather-related natural disasters is mounting rapidly. Reports of natural catastrophes have more than tripled since the 1960s. In 2007, fourteen (14) out of fifteen (15) "flash appeals" for emergency humanitarian assistance were for floods, droughts and storms, five times higher than in any previous year [15]. In Ghana, climate change is being experienced through the rise in temperatures and unpredictable rainfall across all ecological zones [16].

Further, global warming is being predicted to result in changes in precipitation patterns, acidification and humidity [17]. Against this background, the overall impact of climate change on global life support systems remains uncertain. Some areas experience extreme rainfalls leading to flooding; other areas such as the Mediterranean experience a decrease which might lead to drought conditions [17]. According to IPCC, [17] global mean temperatures are expected to increase between 1.4 and 5.8 °C by the end of this century with a corresponding rise in sea level as glaciers melt. Recent observations however show that many predictions about aspects of climate change are near the upper boundary of IPCC's estimates. Sea levels for instance have increased far above IPCC's projected estimates to 30 cm [18].

3.1. Climate Change and Variability in Ghana

Most countries in Sub-Sahara Africa including Ghana are very much vulnerable to climate change and its variability. Based on a study by [19], it was found that an estimate of 35% of the total land mass in Ghana has become a desert area. This desertification is estimated to be proceeding at a rate of 20,000 hectares per annum, explaining why the LUCF sector is contributing more to greenhouse gases emissions in recent times. The activities of mankind in the form of crude farming practices and the persistent

increase in population in Ghana have also contributed to desertification as mankind converts forest and farm lands into residential areas. Extraordinary variability of rainfall patterns within and between the years in Ghana was confirmed by the World Bank [20]. Considering historical data, rainfall was mostly high in the 1960s but this decreased to low levels in the latter part of 1970s and early 1980s. This decline in rainfall patterns still prevails in recent times, as [21] using 20 years data observed that; temperatures in all zones in Ghana are rising, and rainfall has been reducing and becoming increasingly erratic. The impact of climate change is projected to be severe on Ghana, though there will be fluctuations in both annual temperatures and precipitation. Based on the projection by the World Bank, the trend for temperature over the period 2010 to 2050 indicates warming in all regions of Ghana with the highest temperature in the Northern, Upper East, and Upper West regions. However, the region with the lowest temperature is the Brong Ahafo region. These are based on the various climate scenarios carried out by [20]. For instance, based on the scenario, it was realized that temperatures in the three regions of the North will rise by 2.1–2.4 °C by 2050. On the contrary, the predicted rise in the Ashanti, Western, Eastern, Central, and Volta regions will be 1.7–2.0 °C, and that of Brong Ahafo region will be 1.3–1.6 °C.

The agriculture sector of Ghana is very vulnerable to climate change and variability as the sector mostly depends on rainfall. As a result, the sector is characterized by low productivity levels [20]. Households in Ghana differ in terms of their adaptation responses to climate change and variability. These differences may be attributed to the households' livelihood group and asset holding level, and to some extent the ecological zone in which the household is located [20]. Thus, the adaptation practices by households in the northern savannah zone include expansion of area cultivated, dry season gardening, taking on more agricultural tasks by women, cultivation of early yielding and high value crops, diversification into livestock rearing, increasing fertilizer use among others.

According to [22] some of the climatic variations experienced in Ghana and their corresponding time periods are as follows:

- (a) January–July 1976: Very hot weather conditions,
- (b) 1983–1984: Drought—A yearlong of bush fires,
- (c) October–December 1989: Very hot weather conditions,
- (d) 1991: Lots of rains throughout the year,
- (e) 1995: About 40 days of intensive rains,
- (f) 2004: Very cold winds experienced during March–April (Easter) and November–January was very cold,
- (g) 2005: Cold periods resulting in animal deaths,
- (h) August 2006: 1 week of intensive rains, and
- (i) 2007: Lots of rains in August and September.

Also in the years 2012 and 2013, there were severe floods in some parts of the capital city of Ghana (Accra) which made some people homeless and there was also the loss of lives.

Stanturf *et al.* [23] also in their study projected various climate change and climate variation scenarios in different zones in Ghana. These projections are based on the various climate stations they used in their study. The following are their projections about precipitation;

- (a) Accra (Coastal Savanna Zone): Based on their forecast, they realized that the changes in precipitation will range from 52% decreases to 44% increases in wet season rainfall by the year 2080.
- (b) Kumasi (Deciduous Forest Zone): Forecasted changes in precipitation range from 48% decreases to 45% increases in wet season rainfall by the year 2080. Based on their A2 scenario, which generally shows the largest greenhouse gas (GHG) impact, predicts the weakest increase in wet season rainfall, 1.13%.
- (c) Tarkwa (Rain Forest Zone): Forecasted changes in precipitation range from 45% decreases to 31% increases in wet season rainfall.
- (d) Techiman (Forest-Savanna Transition Zone): Forecasted changes in precipitation range from 46% decreases to 36% increases in wet season rainfall. The A2 scenario, which generally shows the largest GHG impact, predicts the largest decrease in wet season rainfall, -2.94%.
- (e) Tamale (Guinea Savanna Zone): Forecasted changes in precipitation range from 36% decreases to 32% increases in wet season rainfall. The Northern Region where Tamale is located is the southern-most region in Ghana to show a consistent trend toward decreased rainfall.
- (f) Walembelle (northern Guinea Savanna Zone): Forecasted changes in precipitation range from 25% decreases to 24% increases in wet season rainfall.
- (g) Bawku (Sudan Savanna Zone): Forecasted changes in precipitation range from 28% decreases to 30% increases in wet season rainfall.

Stanturf *et al.* [23] further projected that sea-surface temperatures will increase in Ghana's waters. This has potential negative implications for the dynamic and critical link between timing and intensity of the coastal upwelling and fishery productivity. Coupled with this, there will also be an increase in sea-level, and this is projected to rise from 0.13 m to 0.60 m by the late 21st century, depending on development scenarios modeled. Using various climate models and three emission scenarios, [23] made the following projections about the temperature in various climate stations;

- (a) Accra (Coastal Savanna Zone): Wet Season, 1.68 ± 0.38 °C by 2050 and 2.54 ± 0.75 °C by 2080; Dry Season, 1.74 ± 0.60 °C by 2050 and 2.71 ± 0.91 °C by 2080 during the dry season.
- (b) Kumasi (Deciduous Forest Zone): Wet Season, 1.71 ± 0.39 °C by 2050 and 2.60 ± 0.77 °C by 2080; Dry Season, 1.81 ± 0.68 °C by 2050 and 2.83 ± 1.04 °C by 2080.
- (c) Tarkwa (Rain Forest Zone): Wet Season, 1.69 ± 0.37 °C by 2050 and 2.56 ± 0.75 °C by 2080; Dry Season, 1.76 ± 0.67 °C by 2050 and 2.76 ± 1.01 °C by 2080.
- (d) Techiman (Forest-Savanna Transition Zone): Wet Season, 1.77 ± 0.43 °C by 2050 and 2.71 ± 0.85 °C by 2080; Dry Season, 1.95 ± 0.79 °C by 2050 and 3.05 ± 1.20 °C by 2080.
- (e) Tamale (Guinea Savanna Zone): Wet Season, 1.84 ± 0.46 °C by 2050 and 2.83 ± 0.91 °C by 2080; Dry Season 2.05 ± 0.75 °C by 2050 and 3.18 ± 1.18 °C by 2080.
- (f) Wallembelle (northernmost Guinea Savanna Zone): Wet Season, 1.92 ± 0.52 °C by 2050 and 2.96 ± 0.98 °C by 2080; Dry Season, 2.10 ± 0.71 °C by 2050 and 3.27 ± 1.11 °C by 2080.

- (g) Bawku (Sudan Savanna Zone): Wet Season, 1.92 ± 0.53 °C by 2050 and 2.97 ± 0.98 °C by 2080; Dry Season, 2.11 ± 0.68 °C by 2050 and 3.25 ± 1.08 °C by 2080

3.2. Climate Change Variability and Projection in Agriculture Production

The agricultural sector has been very paramount in poverty reduction in most developing countries as majority of rural households livelihood depend on this sector. In Ghana the sector is dominated by smallholder farmers who cultivate about 1–2 hectares of land and produce 80% of the country's agricultural output. In spite of the importance of the agricultural sector, it is the most vulnerable sector in developing countries when issues of climate change are discussed since the sector mostly depends on rainfall to undertake its activities. Thus, climate change has the tendency of adversely affecting agricultural production and food security in Africa ([24,25]). Given the fact that West Africa constitutes about 27% of the population of Africa and 16% of its population are undernourished [26], the impacts of global climatic changes could particularly exacerbate the already poor performance in food production being experienced in this region. In relation to Ghana, the cropping systems are highly varied and this reflects the dynamic adaptations to increasing population pressure, land insecurity, climate variability, and new trading opportunities or markets [23]. As a result, most smallholder farmers in Ghana combine different approaches to meet food security and their cash flow needs. The farming systems that may be combined by these farmers include sedentary and shift cropping systems as well as intercropping and rotational cropping [23]. There are instances where cash crop farmers such as cocoa farmers preserve some of their land to grow food crops to provide food for their household. Most farmers in Ghana engage in intercropping in order to minimize risk of crop failure from drought or flooding (see Appendix 1). With the intercropping system, the risk associated with farming can be spread over several crops and smallholders can make the most of a long growing season during a year of above-average precipitation [23].

Low soil organic matter and limited availability of plant nutrients (in the form of phosphorus and nitrogen) are the main constraints to agricultural productivity in Ghana. These constraints are further hindered in the northern savanna zones by substantial topsoil losses through wind and water erosion. Ghana is one of the world's top producers and exporters of cocoa, and the sector has played a key role in the nation's economic development as it contributes about 3.4% to GDP [27]. Cocoa production also accounts for 70%–100% of household incomes of cocoa farmers in Ghana [28]. The importance of this sub-sector suggests that any impact of climate change on the suitability to grow cocoa in Ghana will not only affect farmers' livelihoods and incomes, but it will also affect the economy as a whole. According to [29], about half of the cocoa in Ghana is grown under low shade and this practice is a form of sustainable land use with environmental, biological and economics benefits. Due to the projected increase in temperature, there will be a serious reduction in the suitability within the current cocoa-growing areas in Ghana by 2050 [30]. This increase in temperatures will increase evapotranspiration of the cocoa trees. According to the International Center for Tropical Agriculture [30], the increase of the maximum temperature of the warmest month and annual temperature range will impact negatively in cocoa-growing regions by 2050. Based on the projections of CIAT for 2030, suitable areas for cocoa production will start shifting and this will mainly affect the southern area of Brong Ahafo, and Western regions in Ghana. Further, conditions similar to the current climates of high temperature will remain only in the areas between Central, Ashanti and Eastern regions. However, the remaining cocoa growing

areas will still be suitable to grow cocoa, although they will be less suitable than now. CIAT [30] predict that “by 2050, cocoa production will become concentrated in two areas in Ghana, between the Central and Ashanti regions, and in the mountain ranges of the Kwahu Plateau between the Eastern and Ashanti regions.” Similarly, [19] using a General Circulation Model (GCM) and Simple Climate Model (SCM) projected a decline in rainfall for the years 2020, 2050 and 2080. With this decline in rainfall it expected that cocoa output will decline from the year 2020 to 2080.

The production of rice accounts for 15% of agricultural output and 45% of the total area used in cereal grain production in Ghana [23]. In the production of rice, farmers mostly make use of irrigation, rain-fed lowland and rain-fed upland systems. So in years of extensive drought, rice production will be low in the country. Based on the projected high temperature and low rainfall in the years 2020, 2050 and 2080 the suggestion is that rice production in these years is expected to be low. A study carried out by [31] suggests that in West Africa there is expected to be a small variation in crop production for the year 2030. Rice is expected to experience the most variations (that is, -8%). Further, wheat production is predicted to decrease by about 99% in West Africa for the year 2080. However, maize will experience a smaller response to climate change as productivity reduces by the range of 1% to 7% [31]. In order to improve rice production and other crop productions [23] recommend that the existing smallholders should be transformed into commercial operations and this will require increasing land holdings. In addition, farmers should replace the traditional grass fallow with short-duration leguminous cover crop fallow which should be accompanied by increasing mechanization to replace the labor needed to farm the larger acreages [23].

Similarly, root crops are vulnerable to climate variability as evidenced by obviously lower yields during drought periods and less dramatically by year-to-year variation in productivity. In Ghana, the impact of climate variation on crop is evident in the year 1990 where crop production suffered or reduced due to drought [19]. Climate variables such as rainfall and mean average temperature does relate to root crop yield variability [19]. Based on a test carried out, it was realized that in Ghana there is a strong positive correlation between total rainfall and root crop yield. However, though there is a positive relationship between root crop yield and average temperature, this relationship is weak. Using different climate scenarios [19] projected that yields of cassava and cocoyam are expected to reduce with the rate of reduction increasing with time or rise in temperature and solar radiation. Based on this projection, it was found that cassava yields are expected to reduce by 3%, 13.5% and 53% in the years 2020, 2050 and 2080 respectively.

In relation to fishery, climate change affects the stock of fish and their habitats. Warmer temperatures influence the fish stock, migratory patterns and mortality rates of wild fish stocks and also determine what species can be farmed in certain regions [32]. These climatic effects on fish have social and economic consequences for individuals whose livelihood is dependent on fisheries and aquaculture. Thus, these effects extend from workers at the fisheries industry to coastal communities to consumers of fish. A study by [33] which compared the vulnerability of national economies to potential climate change impacts on their capture fisheries indicated that Ghana is ranked 25th out of 33 nations found to be “highly vulnerable”. This adverse effect of climate change is responsible for the decline of the fishery sector in the Ghanaian economy; hence, limiting the country's ability to meet domestic demand and threatening the economic and food security of many Ghanaians. The disaster is magnified as “Ghanaian fishermen produce 70%–80% of Ghana’s fish requirements and provide jobs for fishmongers, and many

traders” [33]. Also, fish provides 40%–60% of the protein in the Ghanaian diet and fisheries contributes about 4.5% to the national GDP. Using Artificial Neural Network [32] found that fish stock production is closely tied to climatological factors. Thus, lower catch rates of round sardinella coincided with years of higher sea surface temperature (SST); however, the reverse holds for anchovy. With respect to species like tilapia, catfish and flat sardine, precipitation had substantial effect on the production and total annual catchability of these species.

3.3. Ecology, Land Use and Climate Change Variability

The range of climatic and edaphic zones of Ghana spans from coastal mangroves and rainforests along the coast to savanna in the north. Climate change coupled with destructive activities of men in relation to land use could aggravate desertification in northern Ghana. With the rapid land use due to increasing population, land cover changes suggest the tendency of desertification. This is even worsened by the decline in rainfall, coupled with increasing temperatures which is more pervasive in the northern Ghana; thus, making that part of the country very vulnerable to desertification. Given the host of biophysical and human related issues such as erosive rainfall, soil qualities and fertility, recurring drought, low input, decreased fallow period farming, deforestation, frequent hot bush fires, and overgrazing that persist in northern Ghana, the rate of vulnerability is intensified in the region. Notwithstanding climate change effects being either negative or positive, the current increase in the population growth rate, over-exploitation of natural resources, and overall extensive land degradation in the desertification-prone zones of Ghana is unsustainable. Within the northern savanna zone, the resilience and productivity of the zone will be progressively weakened. With regard to the forest cover, Ghana up to date has no complete forest inventory [23]. Within the 1900s, forest cover was estimated to be 33% of the country. However, this percentage declined by 78% (to 1.8 million ha) in the 1980s, and forest areas are now uncommon. Considering the current trend of decline of the forest cover, degradation is projected to increase to 65.5% of the area by 2050 and this clearly increases the risk of desertification [23]. Similar dramatic shifts occurred in the Forest-Savanna Transition Zone.

Gyasi *et al.* [34] found in their study that there is a close interrelationship between seasonal climate factors and cropping calendar as well as water requirement status and adaptability of the entire vegetation in the Upper East Region of Ghana. In addition, [34] brought to light that the average land areas cultivated have significantly increased, but with same few indicator crops. The excessive land usage is compounded by the continuous and extensive overgrazing by large herds of livestock. With the current low rainfall in the region, there is the likelihood of desertification. These suggest that depletion of the vegetation in Upper East Region of Ghana results from prolonged grazing, intensive cropping and climatic variability. The erratic nature of rainfall in the Upper East Region is responsible for the reduced level of groundwater. Further, the use of fire in the land preparation process also has a negative impact on water [34]. Projection for groundwater for the years 2020 and 2050 are that, there will be a reduction between the ranges 5% and 22% and between 30% and 40% for 2020 and 2050 respectively in Upper East Region.

In the case of the effect of climate change on infrastructure, [35] assess the economic impact of climate change on road infrastructure using the stressor-response methodology. They find that it will cumulatively (2020–2100) cost Ghana US\$473 million to maintain and repair damages caused to

existing roads as a result of climate change (using no adapt scenario). However, when they considered the case where the country adapts the designing and construction of new road infrastructure expected to occur over the asset's lifespan (adapt scenario), the total cumulative cost will increase to US\$678.47 million. This suggests that climate change has the potential of draining the country's resources.

3.4. Climate Change Variability and Projection in the Energy Sector

Energy is an essential element in the livelihood of mankind its benefit to human society cannot be over emphasized. Thus, energy can be seen as an essential input for economic growth, and per capita use of energy is considered to be a key indicator of economic development. Energy use is an important component (as a catalyst) of development, but also contributes to emissions. Thus, various types of energy conversion emit greenhouse gases (GHG) [36]. In reality, the demand for energy typically grows with development, but GHG emissions need not grow at the same pace, as conversion and use of energy can be made more efficient. The efficient use of energy will depend on the accurate estimation of the demand for energy and knowing the factors that affect energy demand. However, the accurate estimation of energy is something which has been ignored in most countries, of which Ghana is no exception.

In Ghana, a greater proportion of total annual energy consumption is from the residential sector and this is about 72% as at 2008. The bulk of this energy demand in the residential sector is from biomass in the form of firewood and charcoal (that is, wood fuel) for cooking (constituting 76%), followed by petroleum products for transport and cooking/lighting (constituting 17%), and electricity use for lighting and appliances (7%) [37]. Although wood fuel products are in themselves renewable and thus carbon dioxide neutral, wood fuel combustion can lead to net emissions when there is no reforestation. According to the [37], 90% of the wood fuel is obtained directly from natural forests and the annual deforestation rate is 3%. With this rate, one can project the deforestation rate for a decade to be in the neighborhood of 30%. The other 10% of the wood fuel is from wood waste in the form of logging and sawmill residue, and planted forests.

The use of electricity has been on the increase as a result of the rural electrification project which has been embarked on by the government of Ghana in recent times. Hydropower is an issue of concern in the contexts of climate change, potential for regional conflict, and national energy strategies [23]. The production of hydropower in the future from Akosombo dam is a bit multifaceted and does not only relate to potential climate change since there are issues of trans-boundary implications. One of the major problems is the conflicting interest by Ghana and Burkina Faso in relation to the Volta River Basin. Whereas, Burkina Faso has and is concentrating efforts in the Basin on improved use and increased retention of water for agriculture, Ghana's primary objective is to keep Lake Volta at optimal levels for power production. Further, the water level in the Volta Lake is highly sensitive to small changes in rainfall as indicated by past meteorological data and hydrological modeling. With the current mixed projection of rainfall based on global climate models, there is uncertainty about the water level of the Lake. Nevertheless, trends from historical data indicate fairly dramatic decreases of rainfall from long-term averages hence lower water level in the Lake. Moreover, the design of Akosombo dam was based on the wettest periods on record affecting optimal power production. This suggests that energy production through hydropower means is very sensitive to climatic factors.

The recent flaring of gas from the Jubilee Oil field in Ghana has created concern and debate in civil society and donor countries. The substantial production of gas from the Jubilee Oil Field brings about the issue of storage, transportation and flaring. Prolonged gas flaring of the Jubilee natural gas produces about 1.5 million tons of carbon dioxide (CO₂) annually, constituting about 7% of Ghana's total national emissions [23]. In a situation where the gas is used in a power plant then more than 13,000 barrels of oil/day are saved and this will avoid 0.9 million tons of carbon dioxide emissions. The total emissions reduction potential from using the gas for power production instead of flaring is 2.4 million tons carbon dioxide equivalent [23].

3.5. Climate Change Variability and Projection on Human Health

Several studies have established the link between climate change variability and human health. For instance [38] assert that changes in climatic conditions are expected to affect the distribution of morbidity and mortality through the physical effects of exposure to high or low temperature. Similarly, other studies have concluded on the impact of atmospheric temperature on the health status of a given population. Woodward [39] postulates that human beings are able to cope well with mid-range temperatures and are normally stressed by temperatures which are 'uncommonly' high or low. Moreover, [40] assess that human beings are able to endure body temperature of about 37 degrees Celsius. Substantial increase or reduction in temperature has the potential of negatively affecting ones body's temperature and metabolism processes. Climate change projections show that, heat waves will become more frequent, intense and will last longer in the twenty-first century [41]. This scenario is not expected to happen only in the Mediterranean regions, but also in the temperate regions which are currently not experiencing heat wave events [42]. The early effect of high temperature usually is reduced physical and mental work capacity, further and sustained exposure leads to exhaustion and heat stroke [43]. These have direct effects on productivity ([17,44]).

Projected increase in temperature and reduced rainfall in Ghana, according to [45] will result in an increased incidence of measles although at the current prevailing climate conditions there seems to be a transient but stable decline. Further, there is an increase in the incidence rate of diarrheal cases due to the decline in rainfall and the rise in the mean air temperature. Moreover, the current high temperature and decline in rainfall pattern makes Ghana prone to guinea worm infestation. Furthermore, [46] postulate that a recent survey reveals that malaria (vector-borne diseases) is on the ascendance. They assert that malaria will increase with extreme temperature in the face of poor drainage facilities. Also, cholera, cerebro spinal meningitis and water related diseases also have potential to increase.

3.6. Poverty, Gender and Welfare Impact of Climate Change

Poverty is a multi-dimensional concept which is very pervasive in most developing countries. The multi-dimensional concept of poverty comprises patterns of income and consumption, health, education and the livelihood of people. This multi-dimensional nature of poverty highlights the possibility of the poor to be vulnerable to the negative effects of the environment conditions in the form of natural resource base, ecological fragility, access to safe water and sanitation [46]. The links between the various dimensions of poverty and climatic change through environmental conditions is represented in Figure 4. This shows that accessibility to natural resources and ecosystem services affects livelihoods, dimension

of poverty; accessibility to safe water and sanitation on the one hand and pollutants on the other affect the health dimension of poverty; and ecological fragility and likelihood of natural disasters affect the vulnerability dimension of poverty. Though there are several causal relationships between the environment and poverty, the focus is to examine how changes in the environment either through nature or man’s activities end up affecting the poverty status of man. It is widely acknowledged that changes will occur in the environment so long as man interacts with the ecosystem. It is these changes that have direct and indirect effects on man. Man also in the quest for survival adjusts to suit the changes in the environment.

Wood fuel is mostly used by rural folks and sometimes even poor people in the urban areas since it is difficult for them to afford environmentally friendly energy sources [46]. Environmental causes have been explained to be some of the fundamental reasons underlying the persistence of poverty. Water pollution by mining companies, for instance, can be seen to be a major contributor to diseases if this water serves as a source of drinking water. Poor sanitation and hygiene practices and lack of access to safe drinking water are major causes of diseases. Incidence of natural disasters such as flood, earthquakes and so on do affect the poor more than the rich since poor people are more vulnerable.

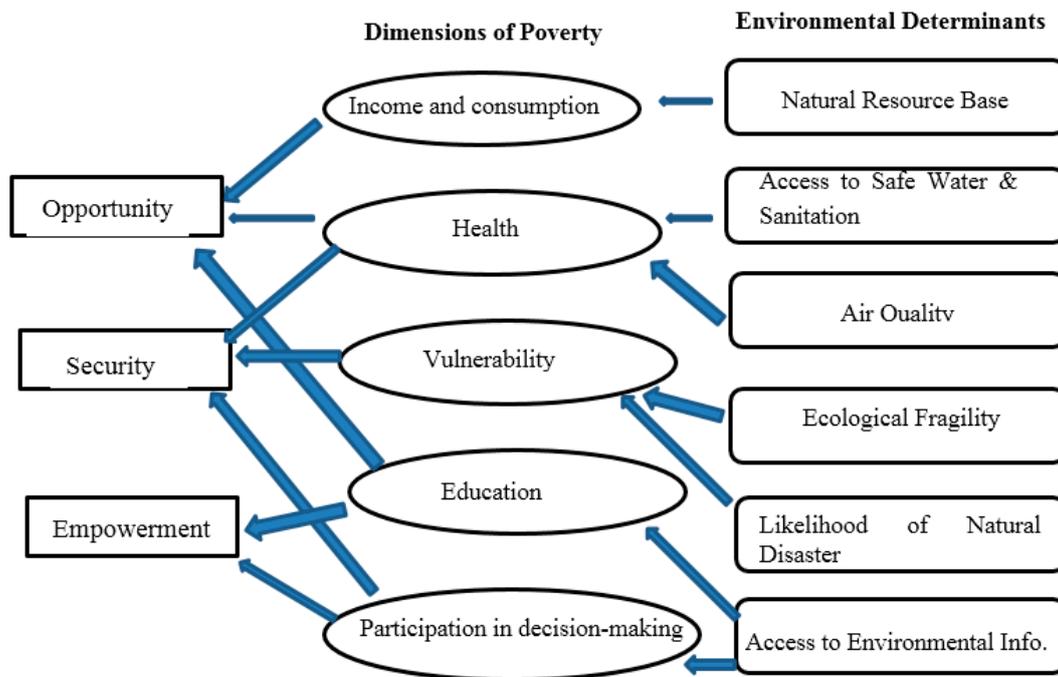


Figure 4. Environment-Poverty Linkages. Source: [47].

Nelson and Agbey [46] finding the links between poverty and climate change in Ghana revealed that there is a strong relationship between climate and poverty levels. Their report shows that ecological zones that have high temperature and low rainfall such as Sudan Savanna, Guinea Savanna and transitional zone have high poverty levels. In addition, they found that most of the District Assemblies with harsh climate conditions have very high incidence of poverty levels. This suggests that harsh climate conditions have the tendency to worsen the poverty levels of these districts and the nation in general. The vulnerability of Ghana to the impact of extreme climate conditions suggests that the poor (crop farmers, fishermen, *etc.*) who depend directly on their immediate environment for livelihood are likely to suffer greatly. Also, [48] present a micro-level simulation to examine the possible impact of

farm level adaptation strategies using spatial dynamic hydro-economic model in Northern Ghana. They find that climate variability has substantial impacts on the poverty and food security status of farm households. Authors in [49] using computable general equilibrium model examine the economy-wide impacts of climate change under four climate projections. They conclude that climate change is found to always reduce national welfare, with poor and urban households and the northern Savannah zone being the worst affected. There is however a wide variation across scenarios in the size of climate impacts and in the relative importance of sectoral impact channels.

In relation to gender, women and men occupy distinct positions in Ghana largely as a result of a gender division of labor within households and the society at large. Women's unpaid labor is crucial for livelihoods and the security of household and family members. This unpaid labor services involve repetitive and time-consuming tasks, such as collection of firewood, water fetching, childcare, sweeping, garbage disposal and cooking, as well as the reproduction of social relations in the household and the community. According to [50], Ghanaian women spend more than two times as much time on domestic work as men. Most women in the rural areas of Ghana are mostly engaged in food crop cultivation and small scale trading in the agriculture sector, while their male counterparts are involved in both food and cash crop cultivation (mostly on a relatively larger scale). Nelson and Agbey [46] assert that women cultivate almost 40% of all land holdings under production in Ghana. Women in urban areas are mostly found in the self-employed informal sectors of the economy, mainly in trading and other service activities, their male counterparts on the other hand have the majority share in the public and private formal sector wage jobs [51].

The recent climate change variations coupled with the risky socio-economic conditions of women in Ghana implies that any disaster (such as flood, drought, earthquake, *etc.*) is likely to have the worst impacts on women. Activities such as bushfires in the savannah region and logging in the forest zones have tended to reduce the composition and density of vegetation. These activities have negative implications of widespread acceleration of erosion, reduced crop yields and desertification [1]. With greater proportion of women engaged in the agricultural sector, it makes the negative impact on them very appalling. Moreover, the sociocultural and land tenure practices in Ghana deny women sufficient access to fertile lands and their plots are the ones which tend to be affected primarily by climate change processes. In most Ghanaian households, the provision of water is mainly the responsibility of women and girls. In their search for water, women usually spend long hours walking long distances to fetch and carry heavy loads of water every day. In times of drought and water shortage, the plights of women are worsened since they would have to walk for many hours in search of water. Depending on varied climate change scenarios, cases of cholera, diarrhea, malaria, malnutrition and heat related deaths may increase. According to [52], pregnant women and children are particularly vulnerable to malaria which also contributes to pre-natal mortality, low birth weight and maternal anemia.

4. Conclusions

The foregoing discussion projects that the temperature in all zones in Ghana are rising, and rainfall has been reducing and becoming increasingly erratic. This climate change and variability coupled with the reliance of the Ghanaian economy on agricultural, energy and forestry sectors makes the country more vulnerable. The negative impact of climate change in the agricultural sector is evident in the

reduction of cocoa, rice and root crops yields. The fishery subsector is also vulnerable to the devastating effect of climate change and variability as the volume of catch is reducing due to climatic factors. Moreover, energy supply from hydro sources which has been dominating in time pass is also at risk due to high temperature and reduction in rainfall. This risk is magnified by the gas flaring at the Jubilee fields which contributes to Greenhouse gasses; hence, intensifying climate change and variability. The health implication of the projected rise in temperature and decrease in rainfall is alarming as there would be an increase in the incidence rate of measles, diarrheal cases, guinea worm infestation, malaria, cholera, cerebro spinal meningitis and other water related diseases. These negative impacts of climate change and variability worsens the plight of the poor, which are mostly women and children.

There have been various measures by policy makers and stakeholders in Ghana to mitigate the potential effects of climate change. However, these measures are not enough and the existence of institutional weakness makes the enforcement of migration and adaption measures a problem. As shown in Table A3, Environmental Protection Agency [19] identified potential climate impacts in various sectors of the economy and also proposed adaptation and mitigation strategies specific to each sector. These proposed adaption and mitigation strategies are good to resolving climate change problems; however, there exist institutional weakness and lack of commitment in their implementations. Stakeholders and policy makers should therefore strengthen the existing institutions and establish new ones in relevant areas where necessary in order to implement the adaptation and mitigation measures outlined in Table A3. Also, commitment to proposed policies is very vital to ensure the successful implementation of these polices. Further, due to the wide variation of the impact of climate change on various sectors of the economy, there is the need for multi-sector approaches that account for climate uncertainty. As suggested by [49] investing in agricultural research and extension and improved road surfaces are potentially cost-effective means of mitigating most of the damages from climate change in Ghana.

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Author Contributions

Both authors contributed substantially and equally to the completion of this study.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Environmental Protection Agency. *Ghana's Second National Communication (GSNC) to the UNFCCC*; United Nations Development Programme: New York, NY, USA, 2011.
2. World Bank. *The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates*. Available online: <http://www.worldbank.org/eacc>. (accessed on 25th January 2014).

3. Owusu, K.; Waylen, P.; Qiu, Y. Changing rainfall inputs in the Volta basin: implications for water sharing in Ghana. *GeoJournal* **2008**, *71*, 201–210.
4. Intergovernmental Panel on Climate Change. *Integrating Sustainable Development and Climate Change in the IPCC Fourth Assessment Report (AR4)*; World Meteorological Organization and United Nations Environment Programme: Geneva, Switzerland, 2003.
5. Al-Hassan, R.; Poulton, C. *Agriculture and Social Protection in Ghana*; FAC Working Paper No. SP04; Future Agricultures Consortium: Sussex, UK, 2009.
6. Athula, S.; Scarborough, H. Coping with climatic variability by rain-fed farmers in dry zone. In Proceedings of the 55th Conference of Sri Lanka: Towards Understanding Adaptation to Climate Change, Melbourne, Australia, 8–11 February 2011.
7. Food and Agriculture Organization. *The State of Food Insecurity in the World 2008*; Food and Agriculture Organization: Rome, Italy, 2009.
8. Ghana Statistical Service (GSS). *Annual Report*; Ghana Statistical Service: Accra, Ghana, 2011.
9. Rosenzweig, C.; Tubiello, F.N. Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. *Mitig. Adapt. Strat. Glob. Chang.* **2007**, doi:10.1007/s11027-007-9103-8.
10. Sachs, J.D. *Common Wealth: Economics of a Crowded Planet*; The Penguin Press: New York, NY, USA, 2008.
11. Maslin, M. *Global Warming, A Very Short Introduction*; Oxford University Press: Oxford, UK, 2008.
12. Keeling, C.D.; Whorf, T.P. *Atmospheric CO₂ Records from Sites in the SIO Air Sampling Network Trends: A Compendium of Data on Global Change*; Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy: Oak Ridge, TN, USA, 2005.
13. Canadell, J.G.; Le Quéré, C.; Raupach, M.R.; Field, C.B.; Buitenhuis, E.T.; Ciais, P.; Conway, T.J.; Gillett, N.P.; Houghton, R.A.; Marland, G. Contributions to accelerating atmospheric carbon dioxide growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 18866–18870.
14. United Nations Framework Convention on Climate Change Secretariat. *Climate Change: Impacts, Vulnerabilities, and Adaptation in Developing Countries*; United Nations Framework Convention on Climate Change Secretariat: Bonn, Germany, 2007.
15. UN World Health Organization (WHO). Protecting the Health of Vulnerable People from the Humanitarian Consequences of Climate Change and Climate Related Disasters. Available online: <http://www.refworld.org/docid/4a2d189e1a.html> (accessed on 11 October 2013).
16. Ministry of Environment, Science and Technology. Message from the vice president and foreword by the minister of environment, science and technology. In *Ghana Goes for Green Growth*; Ministry of Environment, Science and Technology: Accra, Ghana, 2010.
17. Intergovernmental Panel on Climate Change. *Climate Change. The Physical Science Basis. Summary for Policymakers*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2007; p. 18.
18. Kearney, M. Hot rocks and much-too-hot rocks: Seasonal patterns of retreat-site selection by a nocturnal ectotherm. *J. Therm. Biol.* **2002**, *27*, 205–218.
19. Environmental Protection Agency. *Ghana Climate Change Impacts, Vulnerability and Adaptation Assessments*; Environmental Protection Agency: Accra, Ghana, 2008.

20. World Bank. *Economics of Adaptation to Climate Change. Ghana Country Study*; World Bank: Washington, DC, USA, 2010.
21. Cameron, C. 2011, Climate Change Financing and Aid Effectiveness: Ghana Case Study. Available online: <http://www.agulhas.co.uk> (accessed on 20 December 2013).
22. Codjoe, S.N.A.; Owusu, G. Climate change/variability and food systems: Evidence from the Afram Plains, Ghana. *Reg. Environ. Change* **2011**, *11*, 753–765.
23. Stanturf, J.A.; Warren, M.L.; Charnley, S.; Polasky, S.C.; Goodrick, S.L.; Armah, F.; Nyako, Y.A. *Ghana Climate Change Vulnerability and Adaptation Assessment*; United States Agency for International Development: Accra, Ghana, 2011.
24. Food and Agriculture Organization of the United Nations. *Climate Change and Food Security: A Framework for Action*; FAO Interdepartmental Working Group on Climate Change, Food and Agriculture Organisation: Rome, Italy, 2007.
25. FAO. Climate change implications for food security and natural resources management in Africa. In Proceedings of the Twenty-Sixth Regional Conference for Africa, Food and Agriculture Organisation, Rome, Italy, 3–7 May 2010.
26. Food and Agriculture Organisation. *State of Food Insecurity in the World*_[mm1]; Food and Agriculture Organisation: Rome, Italy, 2004.
27. FAO. *FAOSTAT Online Database*; The Food and Agriculture Organization of the United Nations: Rome, Italy, 2008.
28. Ntiamoah, A.; Afrane, G. Environmental impacts of cocoa production and processing in Ghana: Life cycle assessment approach. *J. Clean. Prod.* **2008**, *16*, 1735–1740.
29. Asare, R. *A Review on Cocoa Agroforestry as a Means for Biodiversity Conservation*; Danish Centre for Forest, Landscape and Planning, Royal Veterinary and Agricultural University (KVL): Hoersholm, Denmark, 2006.
30. CIAT: Predicting the Impact of Climate Change on the Cocoa-Growing Regions in Ghana and Cote d’Ivoire. Available online: <http://www.acclimatise.uk.com/resources/resources?resource=68> (accessed on 19 February 2014).
31. Knox, J.W.; Hess, T.M.; Daccache, A.; Perez Ortola, M. What Are the Projected Impacts of Climate Change on Food Crop Productivity in Africa and South Asia? Available online: <http://r4d.dfid.gov.uk/Output/186428/> (accessed on 8 July 2013).
32. Dontwi, J.; Dontwi, I.K.; Buabeng, F.N.; Ashong, S. *Vulnerability and Adaptation Assessment for Climate Change Impacts on Fisheries*; The Netherlands Climate Assistance Programme (NCAP): Accra, Ghana, 2008.
33. WorldFish. Gleaner, fisher, trader, processor: Understanding gendered employment in the fisheries and aquaculture sector. *Fish Fish.* **2010**, doi:10.1111/j.1467-2979.2010.00368.x
34. Gyasi, E.A.; Karikari, O.; Dugan, E. Climate change impacts on land management. In *Ghana Climate Change Impacts, Vulnerability and Adaptation Assessments, under the Netherlands Climate Assistance Programme*; Allotey, J., Mensah, L., Eds.; Environmental Protection Agency: Accra, Ghana, 2008; pp. 110–168.

35. Twerefou, D.K.; Adjei-Mantey, K.; Strzepek, N.L. *The Economic Impact of Climate Change on Road Infrastructure in Sub-Saharan Africa Countries: Evidence from Ghana*; WIDER Working Paper 2014/032; United Nations University's World Institute for Development Economics Research: Helsinki, Finland, 2014.
36. Tilburg, X.V.; Würtenberger, L.; Rivera, R.; Atta-Owusu, F. *Policy Brief: Low Carbon Options for Energy Demand*; Energy research Centre of The Netherlands: Petten, Netherlands, 2011.
37. Ghana Energy Commission. *Wood fuel use in Ghana: An outlook for the future*; Ghana Energy Commission: Accra, Ghana, 2009.
38. Haines, A.; Kovats, R.S.; Campbell-Lendrum, D.; Corvalan, C. Climate change and human health: Impacts, vulnerability and public health. *Public Health* **2006**, *120*, 585–596.
39. Woodward, A.J. Global environmental change and disease dynamics. In *Climate Change and Disease Dynamics in India*; Dogra, N., Srivasta, S., Eds.; TERI Press: New Delhi, India, 2011.
40. Parsons, K. Human Thermal Environment. *The Effects of Hot, Moderate and Cold Temperatures on Human Health, Comfort and Performance*, 2nd ed.; CRC Press: New York, NY, USA, 2003.
41. Meehl, G.A.; Tebaldi, C. More intense, more frequent, and longer lasting heat waves in the twenty-first century. *Science* **2004**, *305*, 994–997.
42. D'Ippoliti, D.; Michelozzi, P.; Marino, C.; de'Donato, F.; Menne, B.; Katsouyanni, K.; Kirchmayer, U.; Analitis, A.; Medina-Ramon, M.; Paldy, A.; *et al.* The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. *Environ. Health* **2010**, doi:10.1186/1476-069X-9-37.
43. Kovats, H. *Climate Change and Human Health: Impacts, Vulnerability, and Mitigation*, 2006. Available online: <http://ebookbrowse.com/haines-kovats-2006-climate-change-and-human-health-pdf-d25908087> (accessed on 5 January 2014).
44. Nerlander, L. *Climate change and health*; The Commission on Climate Change and Development: Stockholm, Sweden, 2009.
45. Baffoe-Bonnie, B.; Agyemang, Y.; Buabeng, S.N.; Ofori, E. *Climate Change and Health, A Report for the Vulnerability and Adaptation Assessment of Ghana's Climate Change*; The Netherlands Climate Assistance Programme: Accra, Ghana, 2008.
46. Nelson, W.; Agbey, S.N.D. *Linkage between Poverty and Climate Change: Adaptation of the Livelihood for the Poor in Ghana*; National Development Planning Commission and Friends of the Earth Ghana: Accra, Ghana, 2005.
47. Bucknall, J.; Kraus, C.; Pillai, P. *Poverty and Environment*; World Bank, Environment Department: Washington, DC, USA, 2002.
48. Wossen, T.; Berger, T.; Swamikannu, N.; Ramilan, T. *Climate Variability, Consumption Risk and Poverty in Semi-Arid Northern Ghana: Adaptation Options for Poor Farm Households*; Elsevier: Miamisburg, OH, USA, 2014.
49. Arndt, C.; Asante, F.; Thurlow, J. *Implications of Climate Change for Ghana's Economy*; WIDER Working paper 2014/020; UNU-WIDER: Helsinki, Finland, 2014.
50. UN Economic Commission for Africa. *Economic Report on Africa: Unlocking Africa's Trade Potential*; UN Economic Commission for Africa: Addis Ababa, Ethiopia, 2004.

51. Bortei-Doku Aryeetey, E. The participation of women in the Ghanaian economy. In *Economic Reforms in Ghana: the Miracle and the Mirage*; Aryeeteh, E., Harrigan, J., Missanke, M., Eds.; Oxford Woeli Publishing Services: Accra, Ghana, 2000.
52. Dampety, P.; Mensah, A.T. *Climate Change Impacts on Women's Livelihoods*; The Netherlands Climate Assistance Programme: Accra, Ghana, 2008.

Appendix

Cropping System	Ecological Zone	Crops	Negatives	Positives
Shifting Cultivation/Bush Fallow/Grass Fallow (clear vegetation, burn; fallow period to restore soil fertility)	Dominant farming system throughout Ghana	Depends on zone	Soil exposed to erosion; fire alters microbial communities and can reduce long-term soil quality; nitrogen is volatilized; deforestation; escaped agricultural fires degrade the rural landscape	Long fallow can restore soil physical and chemical conditions; correct mixture of crops (for example, cereals, and legumes) can augment soil fertility, promote water retention, and prevent flooding. Within a field during the cropping period, farmer may rotate crops (shallow vs. deep rooted, nutrient demand)
Permanent Tree Crop (permanent tree crops usually a monocrop; cocoa is the most extensive)	Rainforest, semi-deciduous forest and transition zones; cocoa cultivation has moved across Ghana, now mostly in the rainforest (west)	Cocoa, citrus, oil palm, avocado, rubber, coffee, mango	Deforestation; increasingly sun-grown cocoa varieties mean no tree cover (i.e., tree removal)	Soil erosion prevention or restoration, groundwater recharge, watershed protection, air quality improvement through carbon sequestration, beautification of the rural landscape
Mixed (integrates bush fallow system with permanent tree crops; intercropping of food crops temporary until trees grow and becomes too shaded)	Rain forest and semi-deciduous forest zones	Cocoa with food crops or oil palm with food crops; taungya to restore forest trees is a variant	Soil exposed to erosion and associated nutrient and water loss	Carbon sequestration, forest restoration
Compound (farms are cultivated within close vicinity of villages and commonly combined with animal husbandry; includes upland and lowland bush fallow and sometimes fadama)	Nothern savanna zones	Cashew and cassava intercrops and food crops such as yam, maize and cassava, tomato, okro, pepper and garden eggs	Soil erosion, leaching and eutrophication are prevalent in this zone;	Permanent agriculture with soil fertility often maintained in the compound fields
Irrigated, Floodplain, Fadama (swamp rice cultivation, irrigated farming, naturally moist valleys and depressions; fadama is a Hausa word for irrigable land)	Nothern savanna zones	Rice, dry season vegetables	Deforestation of riparian or gallery forests	
Special Horticultural Crops (mostly grown for export)	Southern Ghana	pineapples, pawpaw, and exotic vegetables	Soil erosion, Eutrophication, depletion of nutrients from sandy soils.	

Figure A1. Cropping Systems in Ghana, Source: [23].

Table A1. Greenhouse gases emissions by gases. Source: Authors' compilation from EPA [1].

Sectors	Carbon Dioxide	Methane	Nitrous Oxide
LUCF	-37%	21%	30%
Energy	55%	14%	3%
Industrial Process	14%		
Agriculture		42%	64%
Waste		23%	3%

Table A2. Total Emissions/removals by sectors for the period 1990–2006 (GgCO_{2e}).
Source: Authors' compilation from EPA [1].

Sectors	1990	2000	2003	2006
Total (with LUCF)	−16,758.38	12,213.20	23,085.80	23,984.40
Total (without LUCF)	9292.59	13,259.80	15,811.70	18,370.40
Energy	3265.58	5862.31	7926.83	9239.81
Industrial processes	810.57	348.57	57.69	258.29
Agriculture	4578.45	5481.66	5891.89	6600.52
LUCF	−26,050.90	−1046.60	7274.20	5614.00
Waste	637.98	1567.25	1935.28	2271.75

Table A3. Potential Climate Impacts and Proposed Adaptation and Mitigation Strategies.
Source: Authors' compilation from [19].

Sectors	Potential Climate Change Vulnerability	Adaptation Strategies
Agriculture	<ul style="list-style-type: none"> • Harvest failures from improper adaptive strategies • Reduced biological productivity and loss of forest cover • Progressive loss of non-timber forest products • Increased land degradation and loss of cropland • Reduction in livestock size and nutrition 	<ul style="list-style-type: none"> • Development of drought tolerant and flood resistant varieties. • Breeding of early or extra early maturing genotypes. • Developing food insurance schemes; • Educating farmers to plant in low population densities so as to reduce competition for scarce or limited soil moisture • Encourage farm level adaptation such as shift in planting dates and modifying the amount and timing of fertilizer application • Shifts in natural production centres for various food crop areas where comparative advantage can be obtained. • Enhancing food security measures by storing food in national banks
Marine ecosystem and coastal zone infrastructure	<ul style="list-style-type: none"> • Potential risk from sea level rise such as coastal inundation and erosion • Salt water intrusion into fresh water resources • Disruption of sources of livelihoods e.g., fishing and agriculture • Population displacement • Invasion and destruction of mangrove ecosystem, coastal wetlands and beaches along with their associated economic and social importance such as being sites for migratory birds • Loss of habitat of several species including marine turtles • Risk to life, structures and property 	<ul style="list-style-type: none"> • Negotiating regional water-sharing agreements; • Providing efficient mechanisms for disaster management; • Developing desalinization techniques; • Planting mangrove belts to provide flood protection; • Planting salt-tolerant varieties of vegetation; • Improving drainage facilities; • Establishing setback policies for new developments; • Devising flood early warning systems. • The use of setback policies for all undeveloped areas within the coastal zone. This would prevent the construction of immovable structures within hazard areas.

Table A3. Cont.

Sectors	Potential Climate Change Vulnerability	Adaptation Strategies
Human Health and Settlement Energy, Industry and Financial Services	<ul style="list-style-type: none"> • Possibility of emergence of new disease vectors in some areas • Disruption in industry productivity due to possible crises in the energy sector • Disruption in the supply of raw materials e.g., from agriculture, fisheries and forestry • Potential impact on inter-regional trade • Disruption of rainfall patterns will affect Akosombo dam (30% of our energy sources) • Higher risk of property insurance • Possible disruption of banks' lending portfolios 	<ul style="list-style-type: none"> • Establishing setback policies for new developments • Improving drainage facilities • Development of woodlots • Promote and develop energy efficient technologies • Promotion of energy conservation especially in large energy consuming industries • Monitor and control emissions from industries and transport sectors • Promote and develop alternate energy sources such as biomass, wind, mini-hydro <i>etc.</i>
Biodiversity	<ul style="list-style-type: none"> • Possible reduced biological productivity • Alteration of species (flora and fauna) composition in the different ecological zones. • Alteration of vegetation structure 	<ul style="list-style-type: none"> • Reafforestation • Ensure the cultivation of species in the environment that they are adapted to • Establish land use plan for hot spots • Devise flood/drought early warning systems • Provide alternative skill training for fishing communities • Desalinization of water
Water Resources and wetlands.	<ul style="list-style-type: none"> • Loss of biological diversity • Pollution of fresh water resources • Disruption of fishing activities • Reduction in underground water levels • Drying up of river courses resulting from forest losses in headstream areas • Threat to biodiversity e.g., migratory birds 	<ul style="list-style-type: none"> • Devise flood/drought warning systems • Provide alternate skill training for fishing communities • Desalinization of water