17 Climate Change Impacts, Vulnerability, and Adaptation in East Africa (EA) and South America (SA)

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Abstract: In recent decades, global climate change has continued to cause devastating impacts to various places on Earth. Geographic and socioeconomic characteristics in East Africa (EA) and South America (SA) make the regions among the most vulnerable to the current temperature variations attracting several studies with wider implications. Presently, in these two regions, remarkable evidence of climate change includes repeated droughts and increase in dry lands affecting water and food availability for humans, livestock, and wildlife (EA), intensification of climate-sensitive diseases, sea level rise, fast retreat of glaciers on Mount Kilimanjaro in Tanzania, Mount Kenya in Kenya, and Andeans Mountains of South America, change in the rainfall patterns in the Amazon forests and in the whole of EA, and increasing of the frequency and intensity of the El Niño and La Niña phenomenon in the South Pacific that affect both EA and SA, among others. Although these two regions are not major contributors of greenhouse gases (GHGs), the poor conservation of strategic ecosystems through deforestation of the Amazon forests in SA and various forests in EA coupled with intensification of agriculture, land degradation, rapid rates of urbanization and industrialization all driven by rapid population increase are putting a strain on valuable natural resources whose conservation would be critical in mitigating climate change. Adaptation measures have been constrained by climate change impacts. In both regions, poverty is widespread and climate change impacts have jeopardized most poverty alleviation initiatives including realization of some of the Millennium Development Goals (MDGs). Moreover, both regions have a strong dependency on rain-fed agriculture for economic development with hydroelectricity and biomass as main sources of energy. Consequently, adaptation measures are required for all the sectors, but especially in agriculture, health, and energy where the loss of soil productivity, increasing spread of climate-sensitive diseases, reduction of water and energy source supply are already threatening the social and economic security of both regions. Both regions have a wealth of indigenous knowledge and coping mechanisms of various local communities that should be incorporated into conventional adaptation measures of climate change. This chapter describes the main climate change impacts in EA and SA, vulnerabilities thereon, and adaptation measures that offer an opportunity to the two regions to develop in a sustainable way.

Introduction

Increasingly, many people across the world agree that climate change is the latest challenge facing humanity today and that nations must unite in addressing it. The reality of global climate change has been more evident in the recent past as significant scientific evidence clearly shows a warming trend in changing Earth climatic systems. Human development, especially industrialization, is largely blamed for significant release of greenhouse gases (GHGs) into the atmosphere in recent decades that have led to catastrophic changes in, sea level rise, increase in natural disasters, and an increase in global temperatures, among others.

Climate statistics and models indicate that over the course of the past century, the global surface temperature has warmed by about 0.8°C, where 0.6°C is likely to be from the last 3 decades alone [1].

Traditionally, the bulk of the global GHGs contribution was credited to industrialized countries. Presently, major growing economies (Brazil, China, and India) and the transport and manufacturing sectors from other big cities in the developing world have observed a more significant contribution. For other developing countries including those in South America and the East African region, their contribution toward climate change is largely blamed on land use change, land degradation, deforestation and increased household energy needs, especially fuel wood consumption.

Although a few conflicting stands still exist across the globe regarding climate change issues, the heated debates that were not uncommon in the past few years have become less important. Consequently, global efforts toward addressing climate change have thus been seen through the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) which came into force on March 21, 1994 with an overall framework to address climate change through intergovernmental efforts. In addition, the Kyoto Protocol was established alongside the UNFCCC which commits Annex I countries to undertake measures aimed at stabilizing GHG concentration in the atmosphere. All countries of the East African Community (EAC) and South America have ratified both the UNFCCC and the Kyoto Protocol and have actively participated and put mechanisms in place to implement the various agreements accruing from the annual UNFCCC Conference of Parties serving as the meeting of Parties under the Kyoto Protocol (COPs/CMPs).

This chapter has focused on two unrelated regions, EA and SA, that are very vulnerable to climate change impacts but at the same time offering interesting adaptation and mitigation mechanisms humanity can learn from. Major climate change impacts, vulnerability, and adaptation options have been discussed. Some climate change impacts still considered of potential effects elsewhere are already happening within these two regions and hence give a wake-up call to the rest of the world for immediate combating actions. For example, the presence of climate-sensitive equatorial glaciers in the region offers a good opportunity to follow climate change trends and vulnerability. Thus, because of the diverse regional environmental settings and socioeconomical characteristics, the regions offer the best opportunity to understand climate change details and how the developing countries live with climate change impacts, adaptation, and mitigation options thereby. For instance, it is now known that in EA, the ability to adapt to new conditions, exposure and sensitivity changes to climate are determinant factors to the extent to which individual places are vulnerable to climate change impacts [2]. In addition, the regions host some of the least developed countries and one of the emerging economies and thus a good platform for socioeconomical comparisons.

The East African (EA) Picture

Brief Introduction of EA Region

In its widest sense, the EA region includes Kenya, Tanzania, Uganda, Burundi, Rwanda, Sudan, and Ethiopia. Traditionally, the region was known to include only the three countries, Kenya, Uganda, Tanzania while politically; the current East Africa Community (EAC) block hosts the first five countries. The latter block has a rapid growing population currently standing at about 120 million people most of who are directly or indirectly employed in the agricultural sector. The inhabitants of the region have more or less comparable lifestyles and some forms of cooperation, long existed even before and during colonialism. During colonialism for example, the former three countries had a well-developed cooperation in energy, monetary, transport, and communications sectors. To date, such important links continue to exist where they offer important contribution to regional economic growth and livelihood support during needy times like natural disasters which are not uncommon in the region [3].

Biologically, the diverse environmental setting of the region has resulted to a number of endemism and very rich biological diversities. A number of rare species of aquatic and terrestrial ecosystems flourish in the region, both of which have a very big contribution in the economic development of the region. Major wildlife ecosystems of which are internationally appreciated for their uniqueness, flourish in the region, including, among others the Masai Mara Game Reserve in Kenya; Ngorongoro, Kilimanjaro, and Serengeti Wildlife Parks in Tanzania. One of the five internationally recognized centers in terms of high species richness and endemism, otherwise known as biological hot spots are found in the Eastern Arc Mountain forests of EA [4]. The region also hosts a large portion of the Savannah, the richest known grassland in the world. The Eastern Arc Forests and other regional forests make an important contribution in the energy sector in the region in which up to 90% of the total energy usage is biomass dependent [3]. Moreover, the forests and the vast ocean area are very crucial in the control of carbon via the carbon cycle while the diverse water bodies like large rivers and lakes are crucial for the socioeconomical sustainability of the region. These water bodies offer important services like irrigation, hydropower, and domestic water to its fast growing population, especially because the region has frequently been affected by severe water shortages [5].

In addition, EA hosts Africa's tallest mountains (Mt. Kenya and Kilimanjaro) that still harbor rare tropical glaciers. The mountains have attracted several climate change studies that have added regional and extra-regional understanding of climate change trends. Geologically, the region is marked by the presence of the Rift Valley, semiarid to arid regions, and some of the most spectacular waterfalls that have been harnessed for hydropower projects. Furthermore, the region is rich in natural gas, coal, and different precious minerals including diamond, gold, and tanzanite among others [3]. The neutral gas of coal is a notable contribution to the regional energy balance while Tanzanite is globally found in Tanzania only [4].

Demographically, the region is home to thousands of pastoralists who remarkably herd their livestock mostly in the semiarid to arid areas of the region. The pastoralists provide a major portion of the livestock to the markets both within and beyond the region [7, 8] and as such are an important part to the regional gross domestic product (GDP) besides providing employment and important nutritional balance in the region. However, the livestock industry in the region is threatened by periodic droughts, the use of low breeds, and livestock diseases *inter alia*. On the other hand, agriculture is the most important sector in the region considering the number of people it directly employs and its contribution to GDP and foreign exchange. Unfortunately, agriculture is mostly rain-fed and severely impacted by uncertainty in rainfall patterns and intensity. Characteristically, agriculture in EA is largely subsistence, low input, and rain-fed with only isolated cases of large-scale agriculture. This in turn leaves the region vulnerable to repeated crop failures, food insecurity, and increases in food prices [5]. Irrespective of the presence of the most productive soils and numerous water bodies, sadly the region is among the places where malnutrition is very high and periodic food aid has had to be provided. The situation has been made worse by the present climate change where rainfall has continued to be unpredictable, increasingly unreliable, and insufficient.

Meteorologically, EA is located in a complex climatic region in which the diverse topographical and hydrological interactions play an important role. The climate is mostly controlled by interactions between sea surface temperature (SST) forcing, large-scale atmospheric patterns, synoptic scale weather disturbances (namely, trade winds and monsoons), tropical cyclones, subtropical anticyclones, easterly/westerly wave perturbations, and extra tropical weather systems that are superimposed with regional factors like large lakes, topography, and maritime influence [9, 10]. The above complexity renders climatic patterns within the region to change rapidly within a short distance and time. Consequently, the diurnal temperature range varies between 10°C and 20°C while the annual temperature range is only 2°C. On the other hand, mean annual bright sunshine is between <7 to 8 and 8 to >9 h/day in highlands and low lands respectively while the regional mean annual net radiation varies between 450 and 550 cals/cm^2/day. The most important regional wind and pressure patterns include the Congo air stream with westerly and southwesterly airflow, together with the northeast and southeast monsoons. Unlike the Asian southwestern monsoon, both East Africa monsoons are relatively dry while the Congo air stream is humid and associated with rainfall [9]. Generally, East African rainfall is bimodal that is characterized by uncertainty both spatially and temporally. Predominantly, the rainfall occurs during boreal spring and comprises of long rains (March–May) while short rains come in autumn (September/October–December) seasons. The two rain seasons occur when the Inter Tropical Convergence Zone (ITCZ) migrates from south to north through the equator. However, the above pattern varies significantly across the region the uncertainty of which increases toward the dryer zones. In other words, rainfall is more patchily scattered in arid than in mesic systems [10]. Within the region, the fluctuations in rainfall intensity are largely associated with East–West adjustments in the zonal Walker circulations that are linked to El Niño-Southern Oscillation (ENSO). Studies have shown that humid areas in EA will become wetter while dry parts will turn out to be drier. The former will respectively increase runoff while the latter will significantly reduce it. In Tanzania for example, two river basins are already said to have their runoff reduced [9].

In this chapter, the discussions will be limited to the EA political block, the socio-environmental settings of which are considered useful in understanding local, regional, and extra-regional vulnerability and adaptations to global climate change.

Brief Introduction of Climate Change in EA

Although vulnerability to climate change impacts is increasingly becoming of ubiquitous nature, the best way of understanding climate change in EA is to ask “why is the region particularly vulnerable?”

EA is vulnerable because of various reasons, namely, the over-dependency on natural resources; primary production; over-reliance on rain-fed agriculture for livelihood support; low level of development; inadequate institutional and economic capacities all of which leaves many persons vulnerable [5, 11]. Climate change effects like changes in precipitation patterns and rising global temperatures are clearly affecting the region where they already disrupt people’s livelihood, biodiversity, and ecosystems [12]. Recent studies have shown that the region’s economy largely depends on agriculture, livestock, tourism, wildlife, forestry, mining, industries, and marine and coastal resources all of which are climate dependent and directly affected by the ongoing climate variability. Any impact on agriculture, which is the dominant contributor in terms of employment opportunity, income generation, and support to the population, leaves many livelihoods disrupted. In addition to the overdependence on natural resources, the vulnerability also roots from low level of development and generally of per capita income. The majority of the population in the region lives below respective national poverty lines and most of them with less than a dollar per day, especially in rural areas.

Furthermore, socioeconomic inequality within the population increases vulnerability and limit adaptation options to some individuals. The most obvious such inequality could be seen between the urban and rural population in which the latter suffers more from low development, low income, and poor access to public services compared to their urban counterparts [4]. In some places like Tanzania, vulnerability to climate change has even taken a gender dimension in which women are categorized more vulnerable on account of the deep-rooted socioeconomic barriers in the country.

Working with regional climate change projections, the region is set to observe both decreases and increases in rainfall of between 5% and 10% (June–August) and 5–20% (December–February) respectively. Sadly, the projections show that the increase in rainfall may come as a few large storms in early traditional wet season and hence complicate water management, soil erosion, and health services. Several development activities/projects in the region are either directly or indirectly impacted by climate change. This occurs when the variability impairs climate-dependent projects such as forests management, infrastructural developments, and agriculture while indirect impacts happens when socioeconomic projects like health and education are impacted. Regrettably, for a good number of years, most governments in the region did not strategically link climate change and socio-development projects. Climate change factor was not clearly reflected in individual national development plans and policies. Only recently, and after significant climate change impacts, some governments in the region have practically linked the two.

Arguably, the negative impacts of climate change in the region are also complicated by other factors such as rapid population growth, widespread poverty of the inhabitants, human and livestock diseases among others. Even worse, under the current population growth rate, some studies already estimate a doubling in demand for water, food, and rangeland within the 30 years [13]. Such statistics put EA in a very desperate situation and effective measures must be taken sooner rather than later to counter the effects of climate change in the region. EA already has some social stressors which make the region even more vulnerable to climate change and thus limit adaptation ability. Such stressors include the following: governance problems, high population growth, land scarcity in some places, conflicts, and diseases such as malaria and HIV/AIDS.

Given socioeconomical and technological capacity of the region, dealing with climate change will continue to be problematic because of numerous reasons. Most official strategies to livelihoods impacted by climate change are expensive and technical which renders poor implementation. This is where indigenous coping options which are plenty in the region, as will be seen later, could be integrated into the national strategies.

Regional Climate Change Vulnerability

The global climate change impacts like intensification of extreme weather events, sea level rise, alteration in temperatures, and distribution of precipitation are all evident in EA. Within the region however, distribution of the effects of climate change are known to be nonuniform and arguably more noticeable from variations in precipitation than temperature. For example, most studies indicate that the region will warm by between 2°C and 4°C by 2100 which is notably less compared to inner South Africa and Mediterranean northwest Africa. Further projections show that regional warming in the twentieth century has been of the order of about 0.05°C per decade. However, within the region itself, the projected warming is unlikely to be uniform where inner parts of the region are likely to warm more than coastal regions. On the other hand, a number of climate change–related droughts have been recorded in recent years with severe consequences to livelihood support systems and even deaths of both human and livestock [11, 12]. For example, studies have indicated that warm sea surface temperature may be to blame for the recent droughts between the 1980s and 2000s in equatorial and subtropical EA. Interestingly however, historical records in the region show that over the course of the last century there has been a net increase in the amount rainfall [5]. Further studies show that the increasing rainfall and decreasing temperature in presently humid areas may increase river flow by up to 10–20% for example in Uganda [5]. However, more recent studies suggest that whereas parts of equatorial EA are likely to have a 5–20% increase in rainfall from

December to February the region will also observe a 5–10% decrease in rainfall from June to August by as early as 2050. Certain parts of the region are known to be more vulnerable than climate variation than others. For instance, both increase in regional temperature and decrease in rainfall would leave most parts of Northern Uganda and many places in Tanzania with serious water scarcity [13]. Generally, presently wet and dry places within the region will become wetter and drier respectively. In Tanzania for example, two rivers have their flow reduced directly because of the dwindling regional rainfall. Even more worrying, the observations show that the decrease in regional precipitation will most likely occur in the rational dry spell in the region and hence worsen frequency and severity of drought hence desertification. Such relatively drastic changes in precipitation already have many socioeconomical and ecological negative impacts among them reduced agricultural harvests, increased insects and fungal infestations, decreased biological diversity, complicating hydropower availability, *inter alia* [5].

Although climate change affects many biophysical and social aspects in the regions, the following categories considered major issues will be used as a guideline for the discussion under this chapter. Worth noting, some of these impacts have far-reaching influences and tend to trigger other vulnerability.

Natural Disasters: Droughts, Flooding, and Wildfires

Probably the claim that climate change is projected to aggravate frequency and intensity of extreme weather events (El Niño events, storms, droughts, and flooding) and wild fires can superlatively be understood from EA region. The increased frequency and severity of the named natural disasters have in recent years caused injuries, deaths, famine, diseases outbreaks, and even population displacement. For example, the region has in recent years observed severe floods both in urban and rural areas [15–17]. Although considered natural hazards, floods increasingly happen in cities where human activities are to be blamed. Urbanization for example has been observed to cover large areas in cities with roofs, roads, pavements and thus restrict natural flow of water and percolation. Moderate storms in typical East African cities thus end up collecting enough water to cause floods and thus their intensity has been growing as cities expand. Major towns including Nairobi, Kampala, and Dar es Salaam have witnessed periodic flooding which have repeatedly left widespread infrastructural and humanitarian costs [17]. Flooding has also impacted the agricultural sector in which crop fields were swept away, nutrients leached, and top soils eroded. Even more worrying, both frequency and intensity of floods are worsened by the warm ENSO events. For example, the El Niño event in 1997 resulted to heavy rainfall and widespread flooding that was responsible for up to 1.7 m rise in the water level in Lake Victoria and severe damage to the agricultural sector (see Box 17.1 below). The flooding left many famers and pastoralists stranded with massive losses. Arguably as a sign of worsening situation, regional statistics show that between 1992 and 2008 up to 3, 137, 675 USD worth of humanitarian aids were spent on flooding-related disasters. Apart from flooding, drought is another climate disaster that has been very common in the region and is documented to be in close agreement with the regional climate change statistics. Between 1992 and 2008, droughts have claimed about USD 28,383, 288 in humanitarian contributions to rescue lives within the region. Based on regional meteorological data however, drought events may decrease in a few places while at the same time increase in other areas with major potential agroecological implications. Some of the most common implications in the region include desertification and deforestation that have been recorded to increase in many places. Based on the above statistics, it is clear that droughts bring more hardships to the people and have wider economical implication in the region than flooding [17].

Box 17.1. Showing Effects of El Niño in EA

Much of EA observed severe droughts in 1997 that was followed by devastating El Niño rains from October 1997 to March 1998 [18]. The El Niño season was responsible for up to a fivefold increase in rainfall [5] with severe consequences in infrastructure, agriculture, and health problems to both livestock and humans. The available statistics shows that up to 4,000 people died of flooding and many more died due to increased cases of malaria and cholera in the region. In addition, thousands of livestock died as a result of the flooding. The El Niño was economically costly as two major cash crops in many areas within the region; tea and coffee were severely reduced. In addition there were widespread rotting of cereals notably wheat and maize in the region and consequently increased prices of the cereals [9, 19]. Furthermore, the much dependent source of foreign income, from tourisms was as well hampered due to infrastructural problems. Furthermore, movements of farm inputs to farming areas, agricultural produces, and livestock to marketplaces were all impacted with significant increases in production costs.

Apart from that, other recent studies already show a clear linkage between climate change and incidents of wild fire within the region. Cases of bush fire due to periodic droughts and high temperatures are presently not uncommon within the region. One of such studies was done on Mt. Kilimanjaro where apart from the receding glaciers that everybody is worried about, there is a silent danger, periodic fires that are feared to have more ecological consequences than the diminishing glaciers. Because of the periodic fires on the mountain, it is argued that one third of the forest cover has already been lost within the past seven decades alone. The fires on the mountain have been very serious to the extent that it is feared the water sources in the fog interception zone will completely disappear within the next few years. It is thus argued that fires on the mountain may have far-reaching impacts on the eco-hydrological balance of the receding glaciers [20, 21]. Apart from Mount Kilimanjaro, fire events directly connected to climate change have also been observed on other forest resources including on one of the world's biodiversity hot spots, namely, West Usambara and Uluguru Mountains [22]. Incidents of wild fires have also been reported in other regional ecosystems and projected to have more detrimental impacts in countries like Kenya where already a large parts of the country lie in the arid and semiarid areas [23].

Sea Level Rise and the Salt Water Intrusion into Fresh Water Sources

The EA region hosts a long strip of coastal area along the Indian Ocean that is shared by both Tanzania and Kenya. The ocean resource supports millions of livelihood and important cities for regional growth are found along the coast. Hitherto, studies from many parts of the world have shown only a small increase in sea levels and/or reports still treat it among potential effects of climate change. The sea level rise due to climate change can clearly be studied in EA where small islands such as Maziwe Island in Tanzania that was once attractive for tourists, fishermen, and researchers is now most of the time submerged and only habitable for a few hours during the day. Located about 15 nautical miles from a coastal town of Pangani in Tanzania, *Maziwe* Island is a clear wake-up call that the region is already suffering from sea level rise and demands further studies to establish consequential hydro-geological and ecological impacts. Note: Because of its importance and richness, the island was named among the national marine reserves in 1975 and is home to 35 species of corals, more than 200 species of fish and a wealthy of algae, sponges, and sea grasses [4].

Although Maziwe Island is the clearest threat of sea level rise in the region, many coastal towns and cities in Kenya and Tanzania remain at risk from the rising sea level [24]. As seen earlier, most of these coastal towns in the region are of historical importance and attract many tourists every year. Indeed the submerging of the island would have significant socioeconomical and ecological implications like disruption of livelihoods and most importantly the regional GDP. Even more worrying, the sea level rise is already threatening fresh water availability through seawater intrusion affecting millions of coastal inhabitants who mostly depend on ground water for domestic water supply. One such place where sea level rise is threatening such an important source of fresh water is Tanzania in which her aquifers and deltas are known to be at high risk. Other potential risks of sea level rise in the region include coastal erosion, losses of coral reef and mangroves in both Kenya and Tanzania [24].

Impacts on Water Availability, Agriculture, and Food Security

As seen earlier, it is worth mentioning that, even without climate change, agriculture in the region has many serious challenges, among them the overdependence on rainfall and soil degradation. Climate change is of a special concern in the agricultural sector since increasing temperature, changes in precipitation patterns, flooding, and generally water scarcity have all been linked to recent food insecurity in the region. About 80% of EA livelihood depends on agriculture which regionally contributes around 40% of the GDP [25]. Agriculture in EA is highly vulnerable to climate vulnerability which often results to repeated crop failures, lower export earnings, and low domestic revenues *inter alia*. Most EA countries are among the world leaders in terms of food insecurity and climate variability will worsen diminishing harvests [26]. Presently, over 40% of mortality rates among Uganda's children are due to chronic droughts in the country. Many more children across EA are either stunted or underweight because of climate change–related malnutrition [27].

Research has shown that the overdependence in rain-fed agriculture has been leaving many rural livelihoods vulnerable to food insecurity partly due to the recent shift in growing season within the region. Although climate variability has been blamed for the worsening food insecurity, the vulnerability in the agricultural sector is also complicated by heavy reliance on the subsistence farming by the majority of farmers [5]. Note: African agriculture is the slowest in terms of productivity increase. Thus, global warming will only add tension to the already overstretched region and hence likely to affect even a greater number of individuals.

Box 17.2. Showing Potential Impacts of Climate Change on Agriculture

Tanzania is likely to lose up to 10% of its grain harvest per year by 2080 [22], among them, corn, which is a staple food and traditionally the most important source of carbohydrate in Tanzania. Already farmers are witnessing a significant decline in corn harvests and have attempted to grow other crops in its place. Should [CO_2] double and temperature increase by between 2°C and 4°C, an average of 33% of maize harvests is likely to be lost by as early as 2075 [4]. In some places in central Tanzania, up to 80% decreases in the maize harvest have been linked to climate change [4, 22]. In Tanzania, the flood and/or drought-related famines have increasingly been common since the mid-1990s.

The recorded slight increase in temperature and decrease in rainfall within the region have already claimed many victims in terms of food insecurity. For example, the recorded decrease in rainfall of between 50 and 150 mm between March and May from 1996 to 2003 was observed to have a corresponding decline in long-cycle crops in the region. As a result, many households abandoned maize (one of the long-cycle crop) the harvest of which directly depends on the availability of enough rainfall during the mentioned season above (see Box 17.2 above). In recent years generally, drought has been observed to decrease water supplies with consequences in reduced crop productivity and the associated widespread famine in Northern Kenya and the Southern and central parts of Tanzania (see section "Natural Disasters: Droughts, Flooding, and Wildfires"). Another drought-related disaster could be traced in Rwanda where in 2005, the country observed massive crop failures in the Eastern province. In addition to the decrease in the amount of rainfall, agricultural systems in certain parts of EA have also been affected by too much rainfall. Equatorial EA have particularly been receiving increased amount of rainfall during El Niño season which resulted to periodic flooding often associated with sweeping away of crops [5].

Climate change impacts on the agriculture sector will also have significant economic implications via interference with cash crops (Box 17.3 below). In Kenya for example, agricultural losses from three cash crops in coastal areas, namely, coconuts, mangoes, and cashew nuts could amount to about USD 500 million under a 1 m increase in sea level. The three crops also make a significant livelihood to many coastal dwellers in Tanzania and are under more or less similar threats [28].

Box 17.3. Showing Potential Impacts of Climate Change on Cash Crops and the Associated Economic Implications in Kenya

Apart from food crops, climate change is also projected to affect major cash crops in the region with wider socioeconomic implications. Studies have shown that should the temperatures increase by 1.2°C and if the changes in precipitation patterns continue large areas of the world's second producer of tea (Kenya) will be made unfavorable for the crop. The latter would mean interference with over 25% of Kenya's foreign exchange and up to 10% loss of employment opportunity [28].

Impacts on Human, Livestock, and Wildlife Health

Climate variability is ubiquitously known to be central in the reproduction and geographical distribution of a number of disease vectors. For example, recent projections show that a global rise of between 13°C and 3°C would enable mosquitoes to expand their natural range while survival chances of other disease vectors are likely to be increased with increasing rainfall. Within the region, the unprecedented extreme weather events, namely, high temperatures and severe rainfall are blamed for the initiation of malaria epidemic in highland Rwanda, Uganda, Western Kenya, and Tanzania. It is well known that mosquito vectors thrive better under warmer temperatures hence global warming will most likely worsen cases of malaria. Within the region generally, intensity and severity of climate-sensitive diseases, namely, Dengue Fever, Rift Valley Fever (RVF), typhoid, cholera, malaria, dysentery, and a number of respiratory diseases are all projected to worsen with ongoing climate alteration [27].

Malaria

Worsening of malaria cases have been recorded in many places within EA and the epidemic is directly a result of changes in rainfall patterns, higher temperatures, deforestation, and generally environmental degradation [5, 15, 22, 44]. In close agreement to increasing numbers of malaria victims, regional studies already indicate an upward creeping of malaria cases directly because of recent modifications of vector habitats due to climate change [29]. For example, between 1960 and 1980 there were no recorded cases of highland malaria in highland EA the case of which is no longer true in many highland areas like Lushoto and Kilimanjaro in Tanzania. The creeping of malaria into the highlands of EA is of particular concern since the local inhabitants of such places do not have a well-developed immunity against the disease and thus have a relatively increased mortality rate [22, 29]. Worrying predictions exist that more highlanders are likely to be further affected if the current trends will continue. The above trend is already witnessed in many places within the region where on top of climate change which is known to modify vector/microbial adaptations, the situation is also aggravated by regional socioeconomic changes, worsening of food production, and crippling health-care systems *inter alia* [15, 16, 22, 30].

Rift Valley Fever (RVF)

Hitherto, it is ubiquitously known that outbreaks of RVF are usually associated with heavy rainfall and warm temperatures. Within the last decade, several outbreaks of RVF in EA were directly attributed to worsening climate change impacts. Thus, the effects of climate change on human health within the region can further be appreciated by the close correlation between regional El Niño events and Rift Valley Fever (RVF) epidemics in recent years. The observed regional trend has been that during warm ENSO events, the EA highland tends to receive unusual high rainfall which has a positive relationship with the number of recorded RVF outbreaks. Going deeper into historical records would reveal that about 75% of all recorded cases of RVF occurred during the warm ENSO events between 1950 and 1998 [31]. Such statistics give a worrying sign of what is likely to happen if full-scale impacts of projected negative effects of climate change on health sector would occur.

Cholera

The relationship between regional climate change and health sector can further be understood from cholera epidemics. Studies have shown that prolonged droughts often associated with scarce water resources, poor sanitation, and changes in rainfall and temperatures are periodical reasons behind regular out breaks of cholera and other waterborne and diarrheal diseases in EA. Cholera cases are known to be worsened by wet seasons thus any increase in the amount of rainfall as already is the case in some parts of EA (➲ section "Natural Disasters: Droughts, Flooding, and Wildfires") would further elevated cases of cholera. As seen earlier, regional rainfall is projected to increase in coastal areas and Lake Victoria Basin, the named localities above have already witnessed a relative increase in cases of cholera outbreaks [22]. The acute intestinal infection diseases that is caused by *Vibro cholera* can often become fatal and is now declared endemic in Lake Victoria Basin, and has been of repeated occurrence in the region since 1978 [22, 30]. Available statistics show that the disease first caught the attention of EA coastal dwellers in 1836 where it left over 20,000 deaths in Zanzibar (Tanzania) alone and killed many more people in Kilwa (Tanzania), Malindi and Lamu (the latter two in Kenya). As a direct sign of the climate variability factors in cases of cholera outbreak in EA is seen from the fact that cumulatively, more cases of the disease have been recorded over the past 3 decades the same duration in which there has been worsening of climate change impacts.

Recently, the outbreak of poorly known diseases such as Chikungunya fever have also been linked to climate change in EA. It is known that warm and dry climatic conditions precede a typical outbreak of the disease. Following the prolonged drought for many seasons in EA, about 500, 000 people mostly in the coastal areas were reported to be afflicted by the mosquito spread viral disease [32].

Apart from human health, livestock health has also been impacted by climate change in which there could be further infestation of tsetse flies, ticks, snails, and other disease vectors to previously safe zones. The former are already observed to spread to North East Tanzania with the potential of reducing safe grazing range in the areas [22]. Furthermore, the impacts of climate change on healthy systems in EA have even affected wildlife ecosystems. In 1989 for example, large numbers of wild animals died of rinderpest and were directly attributed to regional climate change impacts [22]. Such big losses of wildlife coupled with declining biodiversity due to repeated drought in the region are likely to cripple tourism sector, the major sources of foreign currency in the region.

Impacts on Environment: Deforestation, Fisheries, Biodiversity, Wildlife, Ecosystems, and Sea Water Intrusion into Fresh Water

Although major impacts on biodiversity in the region is presently believed to come from humans via overexploitation of natural resources and land use change, recent climate change scenarios have equally been threatening the biodiversity. Already studies show that there are changes in the migratory roots of wild animals in several precious ecosystems of in EA. Even more worrying, studies have shown an upward shift in vegetation composition in major mountains in the region particularly on Mount Kilimanjaro. Generally, the climate variability already has its detrimental effects in dynamics of regional biomes and biodiversity integrity and richness.

Although most of the tropical fishes have adapted to warm waters, most of them might not survive temperatures beyond their critical thermal maxima due to recent climate change trends. The population of important fish species (*Tilapia mariae*) that occur in EA and used as important source of protein are likely to be affected if their preferred temperature (between 25°C and 33°C) will be exceeded. This particular species of fish has a thermal maximum of 37°C beyond which they will not survive [33, 34]. Ecologically however, global warming might have even more effects as any such ecological imbalances will disturb the ecosystem and might result to losses of many more species. Other studies show that due to recent climate variability impacts in Lake Tanganyika there has been a 20% decrease in primary production estimated to correspond to about 30% of fish yields [33].

In addition, researchers are already worried of the effects of climate change on the hydro-geochemistry of water bodies in EA that have a potential of significantly decreasing fish populations. Regional studies show that any slight increase in temperature is likely to affect the amount of dissolved (O_2) and the limnology of major lakes in the region [35]. Already worrying studies show significant effects might occur in Lake Tanganyika and Victoria. The latter lake has in the 1980s observed massive deaths of fisheries due to low levels of dissolved oxygen as a result of decreased turnover in the lake [4]. It is widely believed that the trend is likely to be the same in other lakes in the region and calls for ecological studies to be carried so as to establish the situation. Any escalation in the effects of climate change on great lakes fisheries will have major socioeconomic implications as the lakes offer an important source of employment, food to millions of people within the region, and even foreign exchange [4].

Even more worrying, among the negative impacts of climate change that are already witnessed in EA include the problem of species invasiveness. It is already known that invasive species have better adaptive ability to climate change which puts them in a better competitive situation compared to other species. The latter is very worrisome as EA region has already witnessed a number of exotic species becoming uncontainable with detrimental ecological implications. Very delicate forest ecosystems in the Eastern Arc Mountains, like the East Usambara forest reserves are already struggling with ecological impacts of several invasive species including *Lantana camara* and *Maesopsis eminii.* The problems of species invasion are not limited to terrestrial ecosystems; marine ecosystems have also witnessed a number of invasions including the water hyacinth and Nile perch in Lake Victoria. Studies show that the region may further be victimized by more colonization of invasive and other exotic specifies directly because of the ongoing global climate change [4].

Although climate change is not the only problem affecting regional ecosystems, combined with other factors like overexploitation of resources and particularly land use changes (destruction of habitats), may result to severe effects to regional biodiversity. The latter has directly affected forest resources and availability of important products like fuel wood has been significantly affected. In addition, regional desertification has also been observed to expand.

Climate Change and Energy Crisis in EA

In order to be able to get a better picture of how the global climate change is complicating availability of energy in EA, the following basic is information is considered vital.

EA is blessed with a rich mixture of energy varieties that can be generalized into natural gas and coal in Tanzania, geothermal energy in Kenya and Tanzania, numerous hydropower sources, significant biomass in nearly all member countries, and recent discovery of oil reserves in Uganda and potentially in other countries. There are also rich potential for wind energy, biogas, and solar power in many places within the region [3]. Within EA however, low level of regional development is clearly reflected in the energy characteristics and can statistically be studied from the percentage (%) energy consumption characteristics (➔ *Table 17.1*).

Table 17.1

Showing levels of energy consumption in East Africa (EA)

Country	Petroleum (%)	Electricity (%) (major source of electricity)	Biomass (%)	Others (Natural gas, solar power, wind power, etc.) (%)
Kenya	21.0	3.0 (Mainly from hydropower, petroleum, and geothermal energy)	75.0	1
Uganda	6.1	1.1 (Mainly from hydropower and petroleum)	92.8	–
Tanzania	8.0	1.2 (Mainly from hydropower, natural gas, coal, and petroleum)	90.6	0.3

In EA, the effects of climate change on regional energy stability can be observed from diverse angles. These include reduced availability of biomass, diminishing/dwindling water flow for hydropower generation, and most importantly destruction of infrastructures (roads, railways, electric poles) needed to transport and distribute various forms of energy.

From the table above, it is clear that the energy balance in all countries is largely dominated by biomass (mostly fuel wood, charcoal, and agricultural wastes). Since the effects of climate change include desertification this is where it possess its effects on the major source of energy. Wood is increasingly becoming rare in many places due to both human pressure and climate change (desertification), see section "Impacts on Environment: Deforestation, Fisheries, Biodiversity, Wildlife, Ecosystems, and Sea Water Intrusion into Fresh Water" above.

One potential mitigation option in the region's energy supply would be to embark on renewable which are not limited. However, the inclusion of the renewable into the energy mix has not been of any significant contribution in comparison to the massive potentials available among other reasons due to high initial costs involved and poor availability of necessary technologies [3]. A few promising attempts however exist in Kenya and much less in other countries where more than 150,000 solar PV units are installed contributing to over 5 MW to the country's power needs. Kenya is again leading in terms of wind energy harvesting where some 450 kW wind power system is already installed. Other countries including Tanzania have already identified several potential locations where wind is abundant round the year and some implementation attempts are ongoing [3]. On the other hand, biogas would be another potential source of energy in the region on account of presence of many livestock. However, biogas technology has been around in the region for over 20 years but its implementation has faced similar problems like solar energy. Isolated hope exists in Uganda and in other countries where a few plants have been installed and running. Interestingly, Uganda has also been a leading player in terms of power generation from industrial biomass residues. Promising units of power are currently being produced in three different sugar mills in the country. Kakira sugar works for example, is currently producing 2.5 MW and plans to produce 15 MW when the unit is fully running. Tanzania has comparable installations in Kilombero Sugar Company with a few other potentials in other sugar industries like Mtibwa [3]. Efforts can still be made by individual governments within the region to invest in renewable energy as the current installation is mostly from private sector. Strengthening of such renewable energy sources into regional energy balance would help in dealing with periodic shortage of power due to repeated droughts in hydropower basins within the region which have hampered many developments projects [3].

Although EA is desperate in meeting its energy demands, if not carefully planned some adaptation to climate change impacts on energy sector are likely to leave the region to follow the destructive way as currently the situation is in Asia, particularly China. The recent incorporation of coal energy as a source of energy in Tanzania is seen to be as one adaptation options. Poor technology of harnessing energy from coal may add regional contribution to GHGs. The country has about $1,200 \times 10^6$ metric ton of proved coal reserves which could meet most of the energy needs in country and potentially of the neighboring countries. Already the country is contributing about 6 MW to the national grid from coal and the plan is to increase production to about 600 MW as an adaptation to the drought-prone hydropower. Given the low level of technology in the country however, the capitalization of coal into the energy mixture is likely to contribute further to the problems of global climate change [3].

Concomitant with the effects of climate change on availability as seen on biomass, hydropower is also periodically affected by drought the frequency of which has been very high in the recent years. Like the rest of EA countries, Rwanda is also facing power shortage because of the impacts of climate change in its hydropower plants. For example in 2006, the country spent 65,000 USD per day to generate emergence electricity because the Rugezi wetland had its water reduced to very low levels. Although, the 1997 El Niño triggered heavy rain and subsequent flooding in many places in EA it left certain parts of Kenya with severe drought that badly disrupted hydroelectricity power generation [34]. In nearly all countries in EA, hydropower generation has suffered from climate change–related problems, namely, low water levels and siltation [3]. Worth noting, the proportion of electrification in the region is very low among other reasons due to financial constraints to expand the network, high prices of electricity, and generally low level of development [3].

Livestock Sector

EA region is home to thousands of pastoralists. Interestingly, most livestock are mainly found in drier part of the EA like arid to semiarid regions. Worth noting, the dry lands comprises of about two-thirds of Africa's land in which about 50 million people depend on livestock and/or dry land agriculture. Although, climate variability is a common phenomenon of most dry lands, in Africa and particularly EA it has particularly influenced ecosystem structures and functions and consequently land use and lifestyles. It is worried that in, arid and semiarid regions, climate change may lead to loss of palatable forage to livestock and more drought-tolerant vegetations that are not suitable to livestock [23]. The major climate change vulnerability to livestock sector in the region comes via repeated droughts that leave the areas with severe shortage of pasture and water (Box 17.4 below). As a result, there has been an increase in the number of conflicts between pastoralists, farmers, and wildlife. The recent droughts have been severe to the extent of triggering communal fighting and even threatened to inter war between neighboring countries. Other vulnerabilities to livestock sector include flooding. In recent years, flooding has been reported to sweep a large number of animals and made pastureland unavailable for livestock. In addition to drought and periodic flooding, livestock industry in EA is also affected by other factors like diseases epidemic, intertribal raiding, and declining pastureland due to rapidly increasing human populations among others.

Box 17.4. Showing Effects of Drought on Livestock Husbandry in EA

In 1997 the whole of EA, observed one of the worst droughts which led to huge economic impacts to the pastoralists [36]. In Uganda, frequency of environmental insecurity, livestock rustling, and intertribal fighting have increased, largely blamed on increased frequency of droughts; thus, pastoralists are forced to move beyond their land areas [14, 36]. It is projected that as a direct consequence of climate change, Uganda may have a significant reduction in suitable areas for dairy farming and entire livelihood of the some pastoralists would be disrupted [14].

Other Sectors

Tourism is a very important regional sector in terms of foreign exchange earnings. Surprisingly, for a very few regional literatures exist patterning impacts of climate change on tourism sector. The effects of climate change on regional tourism mainly come through demolition of infrastructures that support tourism or disrupting the natural beauty of the tourism attractions. Major tourism attraction in the region, namely, Mount Kilimanjaro and Kenya, spectacular ecosystems such as wildlife and natural forests are all threatened by climate change (see section "Impacts on Environment: Deforestation, Fisheries, Biodiversity, Wildlife, Ecosystems, and Sea Water Intrusion into Fresh Water"). Furthermore, major tourism cities like Malindi, Mombasa, Lamu (in Kenya) Zanzibar, Dar es Salaam, Bagamoyo, Mtwara, and Tanga (in Tanzania) all lie in the coastal where the projected sea level rise will have major socioeconomic implications [22]. The livelihood of many people in the coastal areas directly depends on the sector for living. Major infrastructures like hotels and other recreation structures are also threatened by the projected sea level rise [3, 22]. Like in other developmental activities, infrastructures such as roads and railways are very important for the sector but have periodically been swept away by flooding. The recent flooding in Tanzania which was associated with El Niño event swept a large part of the railway and it is estimated that the country would require at least 6 months to fixing it.

Socioeconomic Implications of Climate Change on EA Mountains

Diverse verticality of mountain ecosystem offers numerous microenvironments which in turn creates rich biodiversity. However, mountains are known to be very sensitive ecosystems that are often faced with conflicts between environmental conservation and human activities. Yet, scientific evidence show that most mountains are among vulnerable ecosystems to global warming. Rare mountain glaciers close to equator in a phenomenon that is only present in three regions on Earth: the Ecuadorian Andes, New Guinea, and EA. The latter hosts the two tallest mountains in Africa, Mt. Kilimanjaro (5,895 m) in Tanzania and Mt. Kenya (5, 199 m) in Kenya both of which are socio-ecologically very important to millions of people within the region. Many similarities exist regarding these tropical mountains, both of which are important tourism attractions, serve as important source of water, very rich in biodiversity and probably the most important for now, both are badly threatened by climate change and human pressure [32]. EA Mountain slopes are under constant pressure from both commercial and subsistence farming. The most important climate-related threats on regional mountains include the unprecedented glacier recessions and periodic fires. The disappearance of the glaciers is not limited to the two mountains named above, another mountain in the region, Mount Ruwenzori has observed more less the same trend [32]. Apart from interference with regional hydrological balance, the thinning of the glaciers has reduced the scenic values of the mountains with potential negative ramification to the tourism sector. Historical records show that these three mountains in EA began thinning in 1880 proportional to the drop of water levels in regional great lakes. In this chapter, the impacts of climate change on Mt. Kenya and Kilimanjaro are discussed in the Box 17.5 below.

Box 17.5. Showing Retreat of Glaciers on Mount Kenya and Kilimanjaro and the Associated Socioeconomical Impacts to the Society

Mount Kenya

On account of its uniqueness, Mt. Kenya is included among the list of world heritage sites and nicknamed a water tower in a semiarid region. The mountain contains several remnants of glaciers all of which have been receding rapidly in the recent past (*Fig. 17.2*). For example, the Gregory and Lewis glaciers have been showing unprecedented recession since late nineteenth century. In 1990, there were 18 glaciers compared to only seven left by 2007. Studies show that the deteriorating water resources in the mountain and generally all other resources is attributed first and foremost to socioeconomic changes on the mountain but increasingly significant on climate change consequences and seasonal aridity within the mountain's microclimates. The fast thinning glaciers have badly affected water supply to the already water stresses areas of the region. In addition, nearly all the major rivers in the Kenya begin from mountain, with majority of the water coming from the middle and the summit of the mountain. The water levels in Tana and Athi Rivers among several rivers that originate from the mountain are currently among the worst affected. Tana and Athi Rivers flowing are the main sources of water for the Seven Folk Dams, Kenya's key hydroelectric power generation plant. In addition to domestic use, the water is also used for agricultural activities that are important for the livelihood of the people. Hence, climate change consequences on the mountain could as well have its impacts on energy balance of the country. In addition, the mountain provides an important source of water to more than seven million people in the surrounding communities. Other studies in the region has indicated that reduction in water volume of these two rivers due to glacier disappearance on Mount Kenya, will threaten the lives of over half of the Kenyan population [23].

Mount Kilimanjaro: The Roof of Africa

Like Mount Kenya, Mount Kilimanjaro which is found in Tanzania near the border with Kenya (3°04′S, 37°21′E) offers an excellent opportunity to study and understand regional climate change trends and vulnerability. Because of its importance, the mountain has received a worldwide attention that has attracted a series of studies most of which giving worrying conclusions about its sustainability as a result of both climate change and human pressure. Arguably, the best way of studying the climate change vulnerability on Mt. Kilimanjaro is offered by its fast thinning glaciers and its implications to the hydrology of the surrounding areas (➋ *Fig. 17.2*). While the historical records show that the glaciers have been retreating since 1850, the current thinning is arguably the most alarming and fastest. Whereas the early retreat was likely due to natural climatic shifts, both the ongoing global warming and human pressure are blamed for the worse retreat ever recorded. Statistics show that there was about 4.2 km^2 of glaciers in 1976 compared to only 2.6 km^2 in 2000. The most recent studies on the mountain suggest that there will be no glaciers left on the mountain as early as 2020. The disappearance of the glaciers on the roof of Africa will have many negative consequences. The water from Kilimanjaro is feeding the Pangani basin where about 3.7 million Tanzanians live and many socioeconomic activities are carried out. The waters from the mountain are used for domestic, agricultural, and even hydropower production on the Nyumba ya Mungu dam. In addition, there are already changes in population dynamics and migration behaviors of species in the fragile ecosystems. Any further deterioration in the ecosystem would mean significant consequences as the Kilimanjaro national park is the number one tourists' attraction in the country. Unfortunately, because of climate variability and human pressure, there has been an increase in the number of fire events burning on the mountain that are likely to further degrade the eco-hydrological balance of the mountain [6]. Recent studies show that the fire is responsible for the ecological shift in species zones within the mountain [4, 21, 22, 32, 37].

Note: Because of its richness and shortage of land in Kilimanjaro region, Mt. Kilimanjaro area is among the most densely populated land in the country, the population of which is comparable to that of a typical city in Tanzania.

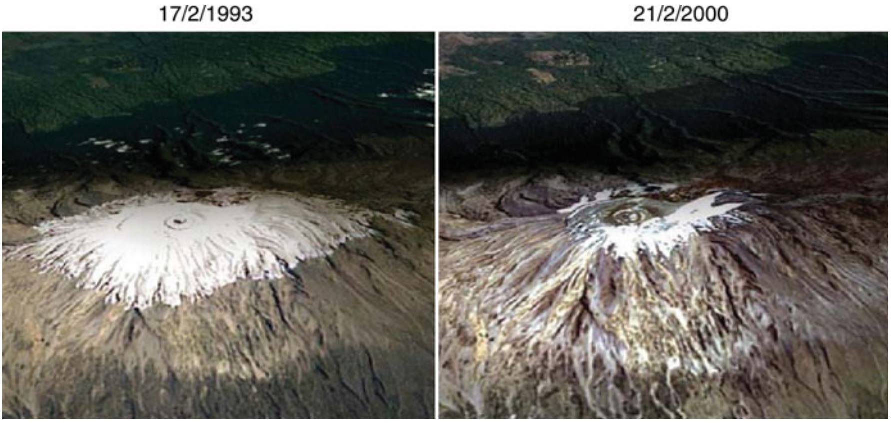

Fig. 17.1
Showing loss of Kilimanjaro glaciers and vegetation cover in a period of less than a decade [4]

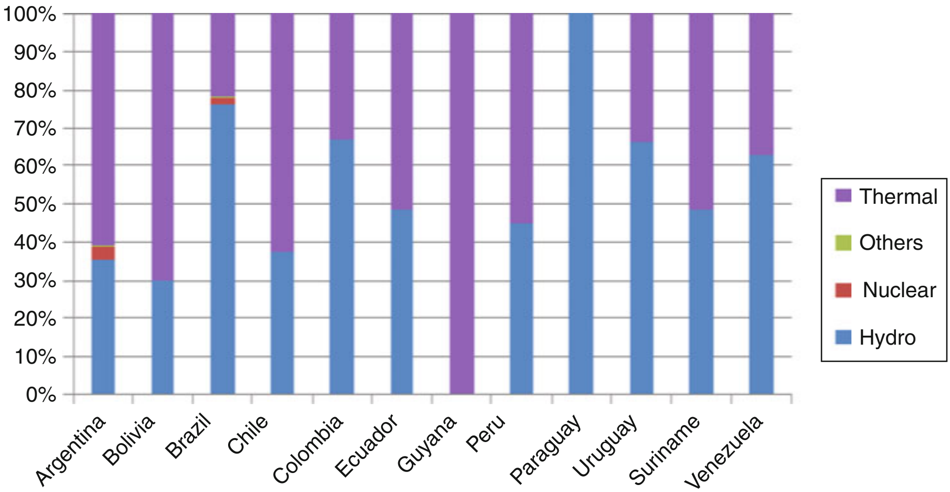

Fig. 17.2
Electricity production structure by country in 2008. Based on information from Latin American Energy Organization-OLADE 2009. Energy Statistics Report 2009. Base Year 2008

Coping with Extreme Climate Events

Indigenous Mechanisms

East Africans have a long history of living with consequences of extreme events like famine, drought, and invasion of locusts among others. Historical records in Burundi, for example, show that during famine, affected population was forced to relocate to less affected places.

In addition to relocation, at times of extreme events, Burundians are documented to have worked as casual laborers in exchange for food. EA region is rich in such strategies albeit most of them need extra-local level enforcement and might only help in a short term and/or for non-severe impacts [4, 5, 14, 22]. Although most of the local initiatives are unlikely to help people in the long term they however do provide important help during disasters. Generally, important lessons can be learnt from such initiatives may be included in regional efforts to combat climate change.

An array of such coping mechanisms is analyzed and their strengths and weaknesses are discussed. The adaptive ability at the local level however differs from regions, households, and/or communities based on their respective environmental settings, socioeconomic backgrounds, and resources availability [5].

Generally, most traditions in EA had strict customs and norms that ensured sustainable utilization of their natural conservation. One of such interesting forest ecosystems management could be traced to Burundi where certain biodiversity elements (plants and animals) were protected under traditional and religious beliefs. Apart from forests resources, such traditional conservation methods were presented for different plant types that were believed to have sacred values. Locally, referred to as *Intatemwa* and *Ikidasha* and translating respectively to what should not be cut and burned, such ecosystems were strictly prohibited from cutting and burning on account of their spiritual benefits. In the same society, felling down of live trees in Kibira forest was also firmly prohibited. Kinira forest, located high altitude, was believed to be a conjunctiva between the Earth and the sky and people generally respected both its virtual and physical services.

In addition, only a few people including the King and members of his kingdom were allowed to hunt in the forest. Generally, the combination of the traditional and religious beliefs above ensured sustainability of many of the sensitive ecosystems.

Such initiatives include the *shamba system* in Kenya and the *Ngitili* of the *Sukuma* agro-pastoralists of Tanzania. The former system works by allowing surrounding communities in the protected government forests to grow short seasonal food crops in the forest patches in which they are also expected to plant and manage trees. Farmers are not expected to establish permanent residence within the patches and after a short time (3–5 years) they usually move and establish the same procedure to other forest patches. No payment is made to the farmers as both parties are beneficiaries in one way or another. The farmers are allowed to use the land the government assisted in reforestation. If this system is well managed and reinforced, it can save the two folds smoothly and help in improved livelihood of the people and the carbon capture and storage [23]. The latter system on the other hand is a common practice among the *Sukuma* agro-pastoralists of Shinyanga, Tanzania. It works by retaining areas of standing vegetation from the beginning to the end of the rainy period. Such areas, locally referred to as *Ngitili*, are usually closed to livestock grazing at the beginning of the rainy season and only made available to livestock during the dry period. The *Ngitili* thus serves to protect livestock from severe drought spells which are not uncommon in this region and at the same time serves to protect the ecology of the areas.

Apart from the strategies above, other communities of the region have other means of making a living during climate-related disasters. Such local level coping mechanisms may include any of the following or their combination: switching to non-farming activities, collection of wild-fruits/vegetables/honey, remittances from migrants relatives and friends, and rarely selling one's assets [15, 16]. Non-farming activities may include things like charcoal burning, handcrafting, casual laboring, and brick making. Although the contribution/income from such activities might be seen insignificant, it provides cushioning household to go through calamitous times like droughts and flooding. Regional lessons show that families that regularly receive remittances adapt better to climate change impacts than their counterparts who received nothing. Likewise the gathering of fruits, vegetables, and honey enable the household members to survive such times.

In the light of repeated droughts and their local experience, some societies in the region have turned into the use of local seed varieties and seed selection as a direct response to drought.

Studies have shown that some local grain varieties, for example, in Tanzania have better tolerance to drought than improved/high yield seed and consequently farmers in drought-prone areas periodically to grow local varieties. Such studies also indicate that the local varieties have longer shelf life than improved seeds.

Apart from that, some famers have replaced common crops like maize and beans with millet, sorghum, and cassava which are known to have better tolerance to drought. In addition, farmers cope with drought by including some livestock in their livelihood and establish some economic ties with pastoralists and markets and practice other off-farm activities so as to diversify survival options [38]. Some farmers use their local skills and change planting seasons when drought is anticipated. When drought is expected farmers have often changed the combinations in their intercropping, to determine when to grow certain crops and switch between crops.

Apart from the survival strategies employed by indigenous farmers, EA pastoralists have also developed several coping mechanisms dealing with periodic droughts (➔ Box 17.6 below). Such strategies include but not limited to economicdiversification, migration to areas with better pastures, having diverse species of livestock, and intentional subjecting of herds to nutritional/drought like stress so as to adapt them to stress period and hence increase their survival chance during disasters [38].

Box 17.6. Showing Impacts of Climate Change on Sociocultural Aspects of Pastoralist Society in Tanzania and Their Subsequent Adjustments

Among the traditionally strict pastoralists society in Tanzania include the Maasai who are entirely dependent on blood, milk, and meat from their herds for nutrition. Interestingly, the Maasai have started to practice crop farming in their means of livelihood [42] and non-pastoral foods like tea, corn, and sugar are increasingly becoming common. One of the reasons why the Maasai alongside other pastoralists in Tanzania have shifted to crop farming is the fact that their means of coping with climate variability to their livestock have been constrained by the current climate change pressure [43].

Adapting Major Regional Sectors to Climate Change

Over the recent decades, the region has faced a number of climate-related calamities, namely, floods and droughts which have crippled livelihood support systems. These have necessitated an array of adaptation strategies at various kinds of sectors including governments, private sectors, and individuals. For a long time however, regional governments had failed to link climate change impacts on development projects. Major adaptation in this chapter will be discussed below guided by vulnerability categories discussed above. Other specific adaptation strategies are also addressed. In recent years also, there has been recognition of the climate change challenges in regional policy issues.

Livestock Sector

Many methods have been suggested in dealing with climate change challenges on livestock sector. The most important adaptation method in practice includes reducing the number of livestock by keeping fewer healthier, more productive breeds. The latter has the potential of reducing pressure on pasture and water resources thus survive through calamitous periods like droughts [10]. Other widely used adaptation strategies include zero grazing and other improved methods of grazing that reduce environmental destruction [4]. The creation of livestock watering centers has a potential of reducing the number of livestock deaths due to shortage of water. The challenge with the latter option is on how to balance the water needs for the animals and avoid concentrating large numbers of livestock on the centers which might end up with further environmental degradation. Moreover, natural resource laws and policies especially on water and land need to be reviewed to allow pastoralists access the resources without triggering tensions with farmers [39]. It is under such circumstances where traditional land laws like the ones in Tanzania may be capitalized and integrated into regional strategies [4]. Finally, improvement of livestock extension services is vital where disaster preparedness information would easily and effectively be made to pastoralists before they occur [5].

Health Sector

The most important means of adaptation in the health sector has been breaking breeding cycle of the disease vectors. The ongoing procedures for the control of malaria for example include improving drainage systems, removing stagnating water points, and bush clearance in residential areas, all of which aim at reducing mosquito multiplication [22].

On the other hand, proper development and implementation of the early warning system for climate-sensitive diseases is another strategy that works better in reducing/controlling disease outbreaks. In addition, inclusion of the local skills on vulnerability, risks and local coping options that have been used by the respective society is very important. For example, some local people within the region have well-developed skills on how to deal with both livestock and human health challenges [41]. Careful integration of local skills into the wider health sector may serve many lives. Tanzania's Government has recognized potentials of traditional medicine and have included it in her medical research. Currently, a relatively well-advanced traditional medical center is fully operational at the Muhimbili National Hospital [22].

Agriculture

Adaptation in agricultural sector probably requires the most attention as inhabitants in the region are among the global leaders in terms of food insecurity. Even more important, climate change is already estimated to have resulted to tripling food crises per year from 1980 to 2000.

Intensification of pests and diseases, changes in cropping timing and shift in agricultural zones are consequences of climate variability that requires immediate actions. Among the frequently suggested adaptation option within the region include, inter alia, the use of fast maturing and drought resistant crop varieties, inclusion of cover crops in the field, conservation tillage practices, and the use of green manure. However, the former strategy would require full involvement of the local people as certain farmers in the region objected certain varieties of drought resistant crops on grounds of their low markets and relatively high labor in their production [22, 40]. As climate-related failures in agriculture system intensified, agricultural sectors took the necessary steps like research in diseases and drought resistant crops, and early maturing crop varieties. Kenya and Tanzania are leading the efforts in such researches and already promising results have been noted. In the former country for example, 14 varieties of maize adapted to low available water are already in the field [23]. Similar efforts are ongoing to other crops, namely, millet, sorghum, beans, and peas. In addition, different regional food security initiatives like national food reserves were created in nearly all countries in EA to help the population during times of disasters. Arguably, as a result of worsening situation, both governments, nongovernmental organizations (NGOs), private sectors, and in some cases United Nations agencies are usually involved in such initiatives. Such initiatives often go down to district level so as to quickly deal with disasters when they occur. However, most of the initiatives have been hampered by lack of enough funding, high food prices, and mismanagement [22].

Clean Energy and Energy Serving Technology

In EA region, most of the energy balance is met from biomass (➲ *Table 17.1*). Any activity that would reduce the current rate of fuel wood consumption would thus help reduce deforestation and hence sequester more carbon. The use of fuel wood–saving stoves (efficient cook stoves) is regionally adapted as a promising strategy in dealing with energy crises. The latter is very important since land degradation, deforestation, and increase in desertification especially in arid and semiarid areas within this region have made availability of charcoal and fire wood very difficult and expensive [23]. Interestingly, the declining biomass has necessitated regional studies on ways of consuming less biomass and higher efficiencies. Several types of fuel wood–saving stoves are in use and are proved to be very efficient. Most of these energy-saving stoves whose technology is simple and generally cheap use between 60% and 70% less fuel wood compared to traditional stoves [3, 4, 23]. The potential of the stoves as a workable solution to reduce regional deforestation has caught the attention of nearly all regional governments, NGOs, CBOs, and other stakeholders and has been introduced to many parts of the region. As a result, the fuel wood efficient stoves are now widely used in public institutions, hotel industry, and households. For example, a recent survey in Kenya has shown that there has been an increase in the number of households using the stoves from 4% to 15%. In Kenya alone, it is estimated that the increase in the use of the stoves would save about 7.7 million tons of fuel wood annually [23]. Other countries in the region are also investing in these stoves and promising outcomes are already reported. In Tanzania for example, efforts are being led by a nongovernmental organization called Tanzania Traditional Energy Development and Environmental Organization (TADEDO) where many stoves have been distributed countrywide [4]. Replication of similar efforts across the region would greatly contribute toward reduction in land degradation and deforestation since biomass contributes over 70% of domestic energy source in the East African region. Apart from fuel wood, other materials, namely, saw dusts, plant residuals, animal droppings, and some commercial wastes have also been used in some of these energy-saving stoves.

In addition to the fuel wood efficiency that has a wide regional advocacy, efforts are also being made to reduce energy use and maximize efficiency in industries. Specific standards are currently operational in nearby countries regarding air quality control and generally environmental protection. Less fuel and high efficiency would all add to reduced GHGs emissions. In addition, there has been limitation in the importation of used vehicles and other machines beyond a certain age limit that have started to be implemented in most of the EA countries which in turn will contribute toward reduction in carbon emission [3].

Other, regional adaptation strategies in the energy sector include cogeneration and bioethanol production. The former mostly involves generation of electricity and heat from bagasse, a sugar cane waste product, by sugar industries. Kenya has currently one registered Clean Development Mechanism (CDM) project in this field, namely, the "35 MW Bagasse Based Cogeneration Project by Mumias Sugar Company Limited (MSCL)." On the other hand, ethyl-ethanol, a by-product of sugar processing that is relatively a clean form of energy that has multiple uses and is currently being explored by various sugar industries in Kenya. Regionally, such relatively clean energy projects are already running in Kenya and Tanzania with the potential of even further improvement to other parts [3].

With climate change, regional cooperation in the energy sector is very important so as to compensate for potential shortfall in energy supplies. There exists a legal cooperation in energy sector within the East African Community (EAC) member states stipulated under article 101 of the Treaty for the establishment of the EAC. The treaty stipulates most legal issues that would ensure a smooth sharing of energy resources where member states are already sharing their energy resources [3].

Generally, coping with climate change–related energy scarcity would require a combination of actions. The most reliable alternative to oil and biomass would be to strengthen the use of renewable energies like wind, geothermal, and solar energy. For example, geothermal energy generation in Kenya has proved to be a reliable and clean form of energy and has made a significant contribution to the national grid [3]. Further exploration of the geothermal energy into Tanzanian side would reduce the overdependence in natural forests and petroleum. Furthermore, investment into the relatively abundant supply of natural gas in Tanzania should be made central as natural gas has proved to be a relatively clean energy compared to oil and coal. Both of these attempts would additionally reduce the little regional contribution of CO_2 emission [3].

Fight Against Disease

Because climate change has been observed to accelerate distribution and intensification of several diseases in EA, several adaptation strategies have been proposed in fighting diseases. Most regional efforts have been concentrated on malaria, the number one global killer that has been responsible for over a million people annually. Because of the high motility rate it inflicts to people, several campaigns have been launched to eliminate the disease. Such regional campaigns range from the use of treated mosquito nets, rising awareness to the general public to the use of insecticides both indoors and in the environment. The latter strategy however needs to be taken with care so as to avoid potential environmental effects. Special attention has recently been addressed in highlands where the local inhabitants do not have the natural immunity against the disease and are thus vulnerable [22]. Other efforts are also addressed to other diseases such as cholera and typhoid fever. Vis-à-vis the latter case, water regional sanitation programs are threatened especially during wet seasons [30]. Apart from human diseases, isolated efforts are also directed toward the control of animal diseases. The latter efforts include the control of disease vectors by the use of insecticides and provision of sound breeding and extension services (However, a few biological control agents of mosquitoes introduced in some areas, for example rice growing village of Mwea in Kenya, should be taken with care and closely monitored and controlled as cases of species invasion are not uncommon in EA [23] (see ➲ section "Impacts on Environment: Deforestation, Fisheries, Biodiversity, Wildlife, Ecosystems, and Sea Water Intrusion into Fresh Water").

Flooding Control

With climate change, flooding calamities have been of repeated occurrence, the latter has necessitated several adaptation strategies across the region. Among such measures include the construction of dams and dykes to prevent flooding. In Kenya for example, such dykes are constructed on river Nzoia and Nyando. So as to reduce vulnerability to people, other efforts include coastal areas conservation and conservation agriculture [17, 23].

Water Harvesting, Irrigation Scheme Development, and Water Serving Technology

Although the region is known for periodic droughts, there are periods of the year where surface runoff and flooding are common and could potentially be trapped for usage during water scarcity. The water which is most of the times wasted can potentially be trapped and used for domestic and industrial usage during drought episodes. Already efforts are being carried within the region where small-to large-scale water harvesting schemes are being done. For example, because of the increasing water scarcity in arid and semiarid regions in Kenya, roof top rainwater collection, and construction of water pans and dams are being facilitated by both the government and private sector [23].

In addition, East Africans have adapted to frequent droughts via irrigation development. As in the case with water harvesting, irrigation projects are well established in Kenya where recently some pastoralist societies have embarked on irrigated agriculture. The Narosura irrigation scheme run by the Maasai from the Narok district stands out to be the best example where horticultural crops are being produced. Similar irrigation schemes are also run in Rwanda, Tanzania, and Burundi. Apart from the efforts above as climate change continued to cause water shortage in the region, water-serving technology has also became a mandatory in many of the agricultural and industrial sectors [23].

Environmental Conservation

As already discussed above, climate change is one of the factors for the recent environmental degradation in EA. In dealing with impacts of climate change on the environment such as soil erosion and water stress from flooding and rising global temperatures respectively, regional governments, private sector, and other stakeholders have taken several environmental conservation steps and management of degraded ecosystems. In some parts of Kenya and Uganda, famers have adapted to farming methods that addresses both soil erosion and water loss. Increasingly, agroforestry, contour farming, and green manure are increasingly becoming common farming methods in many places in the region. On the other hand, special sectors/programs are put in place to address coastal resources in both Kenya and Tanzania [24]. These include the coastal development authority in Kenya and the integrated environmental program in Tanzania [40]. Issues of afforestation and reforestation have also been given significant emphasis in the region. For example, there is a region-wide tree planting campaign that has generally done very well. In Kenya, for example, the Green Belt Movement (GBM) led by the Nobel Prize Laureate, Professor Wangari Mathaai, has received worldwide recognition for planting over 2,000 ha of trees. In collaborating with women groups in other parts of EA, the movement has successfully restored trees in farmlands, community lands, and even on school lands. Such local initiatives need to be assisted so as to deal with the increasing problem of regional desertification. The movement is now in the process of registering some of its afforestation/reforestation initiatives as Clean Development Mechanism projects and is already receiving financial assistants from the World Bank among others [31].

Challenges and Opportunities for Combating Climate Change in EA

Before concluding on this chapter, it would be worth to discuss something regarding regional challenges and opportunities in combating climate change.

The many opportunities available include the potential to develop reliable renewable energies within the region. As mentioned earlier, solar radiation and wind energy are not of short supply round the year [25]. Potentials for geothermal energy are also very promising in Kenya and Tanzania. The former country is already producing a significant amount of electricity from geothermal energy and plans to increase its capacity even further. Albeit, the region has observed a series of droughts and desertification has been reported in a number of places, it has many forests that can serve as important sink of carbon if long-term strategies regarding their sustainability would be ensured. Because of the presence of large land cover in some countries like Tanzania, the potential of afforestation and reforestation exist with the added advantage of the geographical position which favors rapid growth of trees and hence sequester carbon from the atmosphere [27, 39]. Generally, the region has the potential of being among best beneficiaries of the UNFCCC's Reduction of Emissions from Land Degradation and Deforestation (REDD) mechanism.

On the other hand, apart from the challenges discussed so far, high above the list, poverty food insecurity and natural disasters, namely, droughts and floods remain to be exigent. Within the region, poverty is strongly connected with deforestation and generally degradation and could thus limit the successful implementation of mitigation programs such as REDD. The challenge thus is to have effective disaster preparedness, reduce the proportion of populace that depend on rain-fed often unreliable agricultures, have a working health-care system especially in rural areas and the provision of alternative livelihood support mechanisms [18, 31, 40].

The South American Picture

A Brief of South America

South America occupies the landmass of the American continent located in the southern hemisphere, composed of 12 countries and covering 17 million square kilometers. It is bounded by Panama to the north, the Pacific Ocean to the west, and the Atlantic Ocean to the east. This region presented a population of 383 million and a gross domestic product (GDP) of 2.3 billion US dollars by 2007. The total exportations represented US$453 billion while the importations represented U$337 billion. The countries with the highest GDP per capita are Chile, Venezuela, Brazil, and Argentina [45]. In this region 27,602,792 of inhabitants are indigenous (about 7.2% of the region's population), with Peru showing the 46%, Bolivia 21%,and Ecuador 20%. Additionally, for these countries indigenous population represents the 47%, 71%, and 43% of the total respective national population [46].

South America accounts for 27% of fresh water of the world and 8 million square kilometers of forest. The region is the main global food producer and exporter and represents a hydrocarbon (oil and natural gas) offer estimated for 100 years [47]. The main representative organs in the political and economic agreements are the Union of Nations of South America (UNASUR) which consists of all the 12 countries of South America; the Community of the Andean Countries (CAN) with the participation of the main four countries with a territory in the Andean Mountains (Bolivia, Colombia, Ecuador, and Peru), and the Common Market of the South (MERCOSUR) consisted of Argentina, Uruguay, Paraguay, Brazil, and Venezuela. Also, in the region the Amazon Cooperation Treaty Organization was created by the countries with territory in the Amazon Forest (Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Surinam, and Venezuela).

Climate Change Evidence in South America

The climate variability reported in the region is mainly indicated by the precipitation change, which presents an increase in Southern Brazil, Paraguay, Uruguay, North East Argentina, North West Peru, and Ecuador, while some decline is reported for Southern Chile, South West Argentina, and Southern Peru. The percentage of the variation in the precipitation presented a range variation between −5 and +6 in Colombia from 1961 to 1990, while in Uruguay, this tendency showed a positive variation of +20 between 1961 and 2002, which is also completely opposite to the one registered in Chile of −50 for the last 50 years [48].

The temperature variability and its effects on climate events are not only different by region, but also vary according to the season. Bolivia has showed major temperature variations in the humid months, a relationship which is also presented with the precipitation [49]. In the Central Andean Region, the temperature variations registered between 1974 and 1998 are about 0.34°C, which is a 70% more than the global average [50], and maximum temperature variations (°C/10 years) of +0.2 and +0.2 are during the months of December, January, and February in Argentina-Patagonia for the last 50 years, with Argentina central presenting negative variations for the same periods are presented by (−0.2 to −0.8) [51].

The main climate events that have been identified in different ecosystems are strongly related to the Austral Oscillation and El Niño phenomena [52–54]. The interannual oscillation between cold and warm sea surface temperature is known as El Niño and the Southern Oscillation phenomenon (ENSO). This phenomenon presented unusually strong warm events in 1982, 1983, 1997, and 1998, which is believed to have a relationship with global warming [55]. This relationship has also been covered by other studies [56] that studied data of atmospheric CO_2 concentration and the ENSO cycle to analyze the coupled climate–carbon cycle concluding that the terrestrial biosphere and the ocean carbon cycle behave in opposite senses, in which the land acts as source while the sea acts as a net sink.

This is opposite to the dynamic described during La Niña, when sea performs as source and land as sink of carbon dioxide. Moreover, including decadal trends analysis, studies are showing that ENSO could be higher with warmer phases which are increasing with the global warming [55]. On the other hand, studies have suggested that El Niño is activated to reverse positive global warming while La Niña reverse negative trends, concluding as well that ENSO could be sensitive to variation of global temperature but not at the actual value of global warming [56].

The temperature of the surface in the Pacific is linked to the variability of the precipitations, which causes negative trends during warming events, especially in the wet seasons in the Andean region of the North of Bolivia and to the South of Peru, while in the north of the Andean a systematic reduction is recorded in the North-East of Ecuador and in Colombia [52]. Global warming can also cause a permanent El Niño state with major impacts in the Amazonia [67]. Because of the relationship between global warming and ENSO, and the influence of these events with land-climate dynamics, it is important to understand how sea sink dynamics can interact with land sources and the carbon cycle for creating mechanisms due to the protection and regulation of these cycles.

Climate Change Vulnerability in South America

The vulnerability of the region is not a linear process but a complex one related to feedbacks that increase the different risks and the vulnerability in both, the natural and the human systems. In this way, the vulnerable factors described can be direct or feedbacks reactions resulting of the dynamic in social, natural, and/or linked human–natural systems, in which all are, associated to the climate events.

The main threats related to global warming are mainly associated with the climate variations of ENSO. This relationship causes/will cause stronger precipitation and droughts in the South American region affecting the natural hydrological cycles. The responses to the different events derived in South America are demonstrating a high vulnerability in the ecological and human systems. Because of the natural, social, cultural, political, and economical heterogeneity of the region, this vulnerability also varies through all the geography. As a result several risks are recognized for the water resources protection and supply, agriculture, health, energy security, and ecosystems protection especially on the Amazon Basin.

Ecosystems Vulnerability

The coastal area in South America is strongly exposed because the sea elevation, records show ranges in variations over 1 mm per year for Colombia, Argentina, and

Guyana and up to 4 mm/year for Brazil. In Argentina, the coastal area is already affected by the increased precipitations and landward winds [48]. Mangroves are already exposed, and risks associated with hurricanes and the sea level elevation have been recorded. Soil degradation is also worsened with climate change, estimating that more than the 20% of the national territory could be degraded by the year 2050 in some countries like Chile, Ecuador, Paraguay, and Peru [57]. On the other hand, some studies estimated that the resilience of the Amazon Basin climate variations is zero, which in turn means that the conversion of this biome to a drier state threatens the key functionality of this ecosystem (representing the production of the 20% of the global oxygen) [58].

Some researches recognized that climate events, such as hurricanes, can expose the soil to erosion increasing the loss of nutrients. Vulnerability of these ecosystems is related to the Pacific temperature changes, to global warming but also to local climate effects resulting from land clearing or land use change [58]. In Brazil, almost the 50% of the country's rainforest may disappear by 2050 [59]. The effect of the long-term climatic variability has also been recognized in the northern part of the Amazonia where drier conditions have been noted since 1977 [56]. Moreover, the hydrological regime in the Amazon Basin presents more vigorous water cycles as a consequence of the increase in the evaporation and transpiration.

These specific ecosystems sustain water regimes depending on the relationships established between the sunlight, soil moisture, humidity, and cloud formation. As temperatures rise, the mountain cloud forests (also known as nebelwald which are forests with persistent wind-driven cloud) can present warming, affecting the hydrological cycles and exposing the local species to water stresses. As a result of extended dry seasons and lower water supply, vegetation is more vulnerable to fires and droughts [60, 61].

With the 90% of the Andean glaciers located in areas with exposed droughts and the 10% in tropical humid areas; the retreating of glaciers can represent not only a loss of species but also impacts on the society and economy as energy, agriculture, and water supply, which are severally impacted for the present reduction in the ice covering [62]. Studies on glacier dynamics have included different variables to understand the impact of the climate variation and the retreat presented during the last decades. Cloud cover convection, precipitation, temperature, and humidity are related variables that have helped to monitor and estimate the past and future trends of glacier retreat. The temperature variation has increased by 0.11°C every 10 years from 1950 [8], presenting a warming on the Pacific side and moderate variations in the eastern slopes [15]. Furthermore, increasing in the cloud cover is recognized over the North parallel 10°S in wetter seasons (December to February) while to the south of this parallel the cover cloud presents decreasing [52]. The cloud cover and convection has showed a decreasing in the east of the Andes over the Amazons, while information analyzed for the humidity cannot be reconciled with this tendency [63]. The suppression of rainfall in the Amazons is additionally estimated as a result of changes in El Niño and weak Atlantic anticyclone [61].

Socioeconomic Vulnerability

The relationships of the damage ratio with the GDP show that countries like Peru, Bolivia, Ecuador, and Colombia (10%) are more vulnerable than other countries demonstrating a direct link between GDP and vulnerability [49]. This social and agro-economic vulnerability is as well noted in Colombia, Ecuador, Peru, Brazil, and Bolivia by the World Bank [64]. In addition to limited access to insurance, disparities in human development and lack of climate-defense infrastructure, the poverty and low human development are components that increase human vulnerability and reduce the capacity of society to adapt or respond to the climate impacts [65].

Driven by poverty and lack of proper planning, more population is localized on vulnerable zones. In Bolivia, the population growth rate in 1992 was 2.44% increasing 3.47% in the valley region by the year 2000. In the plains, the rates are higher with a growing rate of 3.89% by 1992 and 3.26% by 2000, with the 70% located in the urban area [66]. Additionally, by 1991 the homes under poverty were 78% for the valleys and 70% for the plains [67]. This is a regional tendency where human settlements locate frequently on vulnerable areas, which added to extreme climate events is increasing the risk to natural threats.

Moreover, the vulnerability grows for indigenous population in the region. The major dependency of indigenous and traditional communities is on the natural resources, and because these resources could be more difficult to access or are reduced as a consequence of climate variation, these communities are exposed to negative effects [68]. Also, the location and economical activities of these communities are strongly associated to the services provided by the more affected ecosystems. Not only mountain or dry regions are occupied by different indigenous communities, but also tropical forests and some protected areas are the main zones of indigenous settlements.

It is estimated that large part of Latin Americans living in poverty are indigenous [69]. The traditional and cultural backgrounds of these communities bring them to depend specially on the natural resources, creating dynamics of conservation and local development that can be threatened by the current effects of climate change. Poverty is a common factor in indigenous communities, and because of the loss and degradation of ecosystem services, the access to health systems, education, or information is more difficult for these populations.

The agricultural frontier is expanded as a result of the desertification of the ecosystems and the increasing of urban areas, causing the clearing of forests and the increase of the vulnerability by firing, soil erosion, and local climate variations as well. Despite fossil fuels have been recognized as the main source of CO_2, the changes of the use of land and deforestation are the main causes of these emissions in Bolivia (83%), Ecuador (70%), and Peru (42%) [49]. This tendency is representing a social threat as much as 20% of Brazilian Amazonia's population depends on the region's natural resources and more than four millions of rural inhabitants depending economically on these resources [57].

Resulting from the glacier retreating and changes in hydrological cycles, the water resources are increasingly stressed exposing the population in South America to reduced availability of freshwater resources. Capital cities depend on high vulnerable ecosystems; 70% of the population in Bogota is supplied with water from the Chingaza Natural Park, consisted of cloud forests and paramos, while Quito and Lima depend on water sources from important glaziers as the Antisana and Cotopaxi in Ecuador and the Chacaltaya in Peru [50].

Agricultural Vulnerability

Agriculture is as well one of the main impacted components in South America. This sector is one of the most important in the regional economic development, accounting for 8.6% of the gross domestic product (GDP) [70]. The most extensive droughts and reduction of precipitation in some areas reduce the productivity of crops. In Paraguay decrease in cotton, wheat (by 2030) and soy (by 2050) are expected with sugar cane, cassava, and corn presenting increase in crop yields as a result of the A2 climate scenario (climate scenarios were developed by the Emission Scenarios of the IPCC Special Report on Emission Scenarios, the A2 scenario includes a storyline and scenario family describes a very heterogeneous world). For subsistence farms in Ecuador 1°C of temperature rising can increase crop yields but with a retreating after temperatures reach 2°C, also banana, plantain, and cacao can be negatively affected with a just rise of 1°C for intermediate farms [57]. In this way, it is also projected that small farmers (farms less than 30 ha) will get positive impacts for those situated in cold areas, but those located in warmer regions (Venezuela, Colombia, and the North of SA) may suffer negative consequences [71].

Some projections estimated different scenarios of temperature and rainfall variations to 2100, the first included an increasing of 1.9°C in the temperature and a 10% of rainfall increasing, other two estimated temperatures raisings of 3.3°C and 5°C with rainfall dropping by a 5% and 10% respectively. Following these projections a loss of land value of about 20% (by the year 2060) and 53% (by the year 2100) was calculated in the worst warming scenario, and with smaller magnitudes in the other two. The study underlines the representativeness of the precipitation changes in the final values, with small household farms showing more vulnerability with higher temperature while large commercial farms responded negatively to increasing in the precipitation (as these kinds of farms owned commercial livestock what can be more affected by precipitation increase) [71].

Impacts and Potential Risks Caused by Climate Change

ENSO has been related with malaria outbreaks in South America and childhood diarrheal disease in Peru [34]. The IPCC predicts that the dry seasons can promote malaria, especially in the coast areas of Colombia, Venezuela, and Guyana, while with floods these epidemics are recurrent in the north coast of Peru. Also, prolonged droughts in Argentina, Chile, Paraguay, and Brazil increase the outbreaks of pulmonary hantavirus, while leishmaniasis, leptospirosis, and hyperthermia are outbreaks associated with the climate phenomenon [48].

Power energy stations are presenting decreasing and suspension of the services because of the precipitation changes, increasing temperatures, and longer dry seasons corresponding to more frequent steady El Niño phenomena (see Box 17.7).

Box 17.7. News Summary

February, 2010
Paraguay faces energy shutdowns everyday as result of the heat wave presented in February with high temperatures that also raise the energy consumption overcharging the capacity of the hydroelectrical system. (BBC Mundo, 2010)

October 21, 2009
The drought caused by El Niño has forced to the energy interruptions in Venezuela. The reduction in the main rivers levels that supply the hydropower of different damns demands frequent electricity cut offs in all the country. (IPS, Venezuela, 2009)

November, 2009
Ecuador faces the worst drought in the last 40 years that has reduced the reservoirs of the hydropower centrals and requiring the emergency declaration by the national government in the electricity sector. This situation has also required the increasing in the energy imported from Peru and Colombia. The emergency was clear when the Paute Hydroelectrical Plant reduced the production to 35% of the total demand while the normal condition was of 60%. (La Hora, Ecuador, 2009)
Source: Arce E (2010) Paraguay also has Energy Crisis (in Spanish). BBC Mundo. Available on: http://www.bbc.co.uk/mundo/america_latina/2010/02/100208_1318_paraguay_energia_gz.shtml; Marquez H. (2009) El Niño takes the water, the electricity and the water (in Spanish). Ambiente Venezuela; La Hora (2009) El Niño El Niño is merciless with the countries of Latin America (in Spanish). Available on: http://www.lahora.com.gt/notas.php?key=58448&fch=2009-11-14

This tendency is representing a risk for the energy system in SA as electricity production is mainly based on hydroelectricity (see *Fig. 17.2*).

The present clearing rates and the agricultural frontier expansion are threatening the Amazon forest, a key global ecosystem. The increasing of evapotranspiration caused for higher temperatures will impact water cycles in the Amazon's Basin. On the other hand, with the loss of vegetation and increased temperatures a combination of lower evapotranspiration and precipitation causes a drying effect. Loss of species and ecosystem types shifts are resulting from the global warming and increasing the vulnerability of human communities as well [56]. Furthermore, some features of the human communities settled in the Amazons region result in an increased risk for the conservation of this ecosystem and the sustainability of the human communities.

The high dependence on manual labor of small farmers in the Amazons and the information incompatibility between global and local dynamics increase the difficulty of these actors to develop adaptation and conservation measures [72]. As this ecosystem is one of the main regulators of the carbon dioxide and local climate, and one of the main biodiversity regions in the planet, the current human and natural dynamics are generating a high risk in the loss of these functions, and increasing the effects of climate variation in the region.

Adopting Climate Change Adaptation and Mitigation Measures in South America

The adaptation measures vary in different scales. In Peru, subregional strategies can be developed for the Clean Development Mechanism (CDM) or Adaptation under the National Strategy on Climate Change implemented since 2003. As a result, different actions on water management, food security, risk prevention, or hydroelectricity can be found [31]. Moreover, Colombia is implementing the Integrated National Adaptation Plan (INAP): High Mountain Ecosystems, Caribbean Islands and Human Health [73] supported by a bilateral cooperation between the Netherlands and Japan. Additionally, many studies are still focused on the development of diagnostics and in pilot phases, some transversal programs are found in Bolivia, where a national mechanism for climate change adaptation covering water resources, food security, health, human settlement and risk management, and ecosystems create transversal programs in scientific research, capacity building and education, and anthropologic aspects and traditional knowledge [74].

Adapting to Climate Change

Information management is also part of the adaptation measures. More investments and technological development will take place as much as information is reliable and open markets as result of the people perception on the necessity to adaptation [74]. Counting on reliable precisely and continuous information allow the governments to establish corrective measures for the different sectors. Projects like the Community-Based Risk Screening Tool – Adaptation and Livelihoods CRiSTAL (to assess the systemic vulnerability) or Opportunities and Risks from Climate Change and Disasters-ORCHID (to manage the risk, integrate adaptation, and identify opportunities to reduce vulnerability) are important developments with international support [75]. Also, the Tropical Ocean Atmosphere Program provides observations of the upper tropical pacific from the middle 1990 allowing the implementation of adaptive measures in the agriculture planning, fire prevention, stream flow prediction for hydropower, and with new applications in the health system [48].

The Regional Role in Global Climate Change Mitigation

Mitigation actions in this region are mainly directed for the conservation and protection of forests as clue elements for sinking CO_2. In Colombia the first pilot project on adaptation by the Global Environment Facility (GEF) is being carried out, while Peru, Bolivia, and Ecuador are developing the proposal for the Andean Regional Project for Adaptation aimed at supporting pilot projects on glaciers and watersheds. Additionally, Ecuador is implementing a project through the water governance to reduce the vulnerability on climate change by an effective management of the water sources and better access to information on climate [49].

On the other hand, some projects showed results on the ecosystem services demonstrating the complexity using these mechanisms. In Brazil, after 4 years under implementation of a project to pay for conservation services to small-scale farmers located in the Brazilian Amazons has presented combined results. This program developed by Proambiente has gathered about 4,200 participating families, from which the 42% have reached payments over the R $650 (US$325) per household [59]. Also, the Juma Reserve REDD project has been established to prevent deforestation by the valuation of the services provided for the forests located in the southeastern region of the Brazilian State of Amazonas [76]. The PES (Payment of Environmental Services) presents a varied implementation; countries like Colombia and Ecuador counts on important projects (e.g., the Face Reforestation Program for Ecuador-PROFAFOR (Spanish abbreviation) carbon sequestration program, and the Pimampiro municipal watershed scheme) demonstrating advanced applications, however Colombia presents some disadvantages in the payment to services providers, while countries like Bolivia and Venezuela show a higher skepticism and political barriers [77].

Otherwise, some challenges are recognized for the legal hurdles, this aspect is observed on the Brazilian legislation for the concept of environmental services and their economic value which can be related with the water-use charges that does not place economical value on the water-conservation role of landowners [59]. Also, the complexity on the information related to the scientist and economical integration can affect the real operability of adaptation and mitigation measures. For this case, some studies have estimated that emission from both deforestation and fossil fuel combustion represents the 12% which is 8% less than the one estimated by the Intergovernmental Panel on Climate Change (IPCC) [78].

➲ *Table 17.2* shows the ecological footprint for some countries in South America included in the estimations made by the Global Footprint Network [79] demonstrating the large biocapacity contained in the region and represented by their forests. South America counts on several advantages to develop adaptation and mitigation measures. Peru holds more than 40 projects equivalent to the reduction of about five millions of CO_2 tonnes [49]. The Andean region including Venezuela and Chile counts with 570 millions of hectares of bio-productive area from which 200 millions supply goods and services and absorb their own wastes, representing 370 millions of global hectares valuated in 115,000 million dollars [50].

Table 17.2

Ecological footprint, ecological deficit, and main contributor of biocapacity, by country, 2006 (Elaborated based on information from Global Footprint Network. Footprint for Nations 2010 data tables http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_for_nations/. Accessed September 29, 2010)

Country name	Ecological footprint 2006	Ecological (deficit) or reserve 2006	Main type of biocapacity 2006
Argentina	3.0	4.1	Cropland (33%)
Bolivia	2.4	16.9	Forest (82%)
Chile	3.1	1.0	Forest (53%)
Colombia	1.9	2.0	Forest (57%)
Ecuador	1.9	0.4	Forest (57%)
Paraguay	3.4	7.4	Forest (62%)
Peru	1.8	2.3	Forest (67%)
Venezuela (Bolivarian Republic of)	2.3	0.3	Forest (72%)

The PES offers a great opportunity for countries to develop mitigation programs for the conservation of ecosystems and reforestation. For example, in Pimampiro, Ecuador, a farmer receives 12 $/ha/year for the conservation of primary forest, however, payments can vary for the same land use (a farmer in Heredia, Costa Rica receives 57 $/ha/year for the same land use), the implementation of PES has turned on an opportunity for farmers to develop conservation and productive activities [80].

The Climate Change Challenge for South America

South America CO_2 emissions are relatively low, however, Brazil predominates the emissions of the region while all the countries (excluding Paraguay) are presenting increasing in the emissions, with Bolivia and Ecuador showing an increase of 69% and 79% between 1999 and 2008 relatively (see *Fig. 17.3*).

About the 50% of the ktCO_2 registered by 2012 belongs to energy associated projects (see *Fig. 17.4*). This tendency is demonstrating the important participation in the Carbon Market reached by the implementation of energy projects.

Some projects in South America are demonstrating the potential of the region for implementing alternative energy and reduce CO_2 emissions (*Table 17.3*).

Despite the low participation of SA in the CDM, energy projects represent more than the 80% of the ktCO_2e registered by 2012 in all countries in the region (excluding Paraguay and Uruguay) (see *Fig. 17.5*). SA requires technological transfer to take advantage of the alternative energy potential but better policies should be applied by

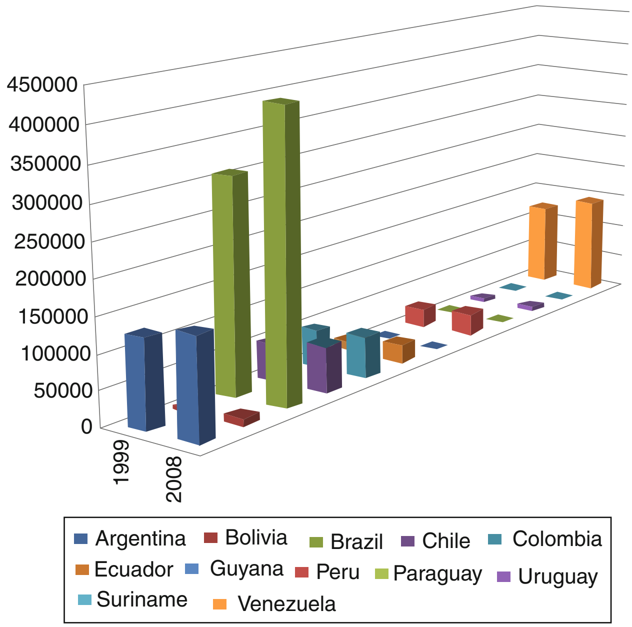

Fig. 17.3

CO_2 emissions (Gg) by country, 1999 and 2008. Elaborated based on data from Latin American Energy Organization-OLADE 2009. Energy Statistics Report 2009. Base Year 2008

participating in Global Carbon Market to achieve technology and resources transfer while protecting natural resources. A good example was given by Ecuador when decided to pledge in a pioneering agreement with the United Nations to refrain from oil drilling in a pristine Amazon preserve in return for some US$3.6 billion ($4.9 billion) in payments from rich nations [81].

Because the ecological sensibility, the sociocultural and economic context, South America is one of the main vulnerable regions in the planet facing climate change. This situation requires more accelerated and practical adaptation programs in the real scenario. Because the main natural and social characteristics bring different levels of risk, also the application of these programs should vary and be approached to different scales.

The main challenge for this region is to understand how global, regional, and local dynamics can impact the different local scenarios. At present, the main aim for combating climate change is to design more effective mitigation and adaptation measures for the specific and unique conditions, not only for the different countries, but also for the different communities and ecosystems contained within them. Policy integration of the countries to transform the natural resources and energy potential into operative projects is required. Regional scales, beyond national boundaries, should be integrated for designing regional actions toward the technological transfer for alternative energy development and conservation programs for vulnerable ecosystems like the Amazons, Glaziers, and forest cloud mountains.

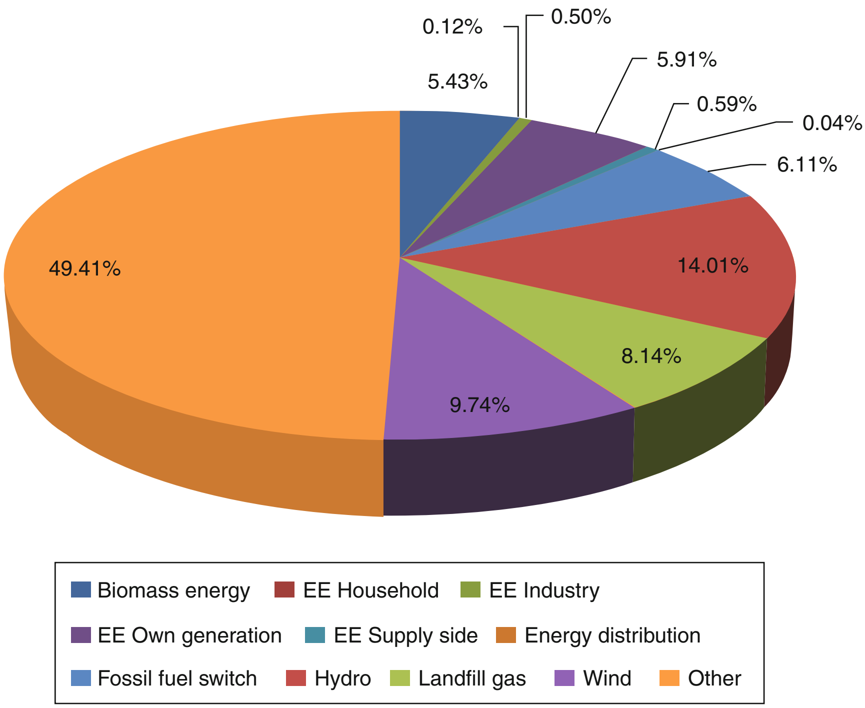

Fig. 17.4

Global sharing of $ktCO_2$ registered by project type by 2012. Elaborated based on information from data available at Carbon Market Data World ETS Database http://www.carbonmarketdata.com/. Accessed February 17, 2011

Table 17.3

CO_2 reduction potential by energy projects in South America (Elaborated based on information from * General Secretariat of the Andean Community, the United Nations Environmental Programme (Regional Office for Latin America and the Caribbean), and the Spanish International Cooperation Agency (2007) and ** Gerardo Siva Dias PR, Ribeiro WC, Sant Anna Neto JL, Zullo Jr. J (2009))

Country	CO_2 reduction potential (Tones equivalent)	Kind of project
Ecuador*	307,000	Not specified
Bolivia*	17.7 Millions	Not specified
Colombia*	800,000	Jepirachi eolic project
Brazil**	84,165	Alta Mogiana Bagasse for electricity produced from fossil fuel energy stations by energy produced from sugarcane bagasse

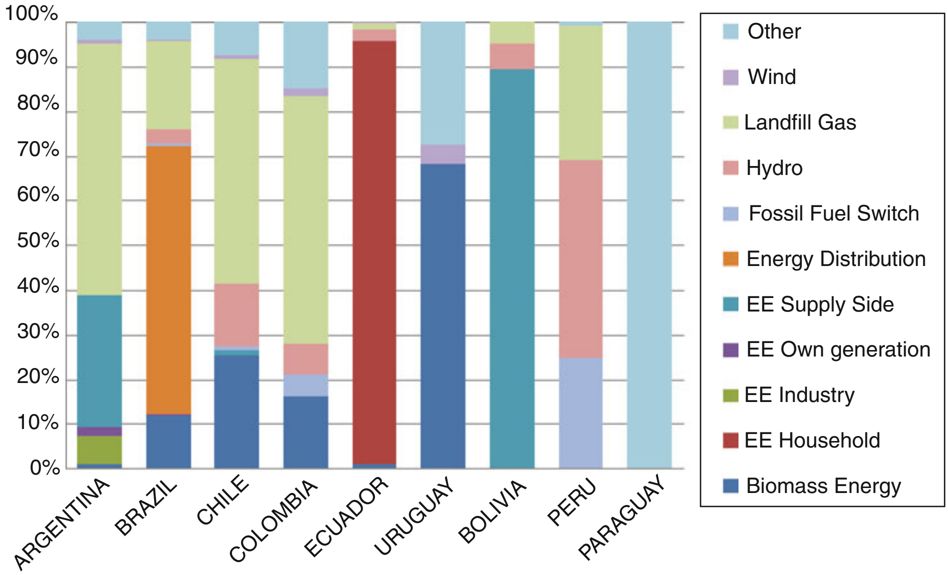

Fig. 17.5

National Sharings of ktCO$_2$e Registered by Project Type by 2012 (Elaborated based on information from data available at Carbon Market Data World ETS Database http://www.carbonmarketdata.com/. Accessed February 17, 2011)

Future Direction to Combating Climate Change in SA and EA

Vis-à-vis the present climate change impacts, it is very unlikely that the negative effects on the environment and people's livelihood will improve any time soon. The latter necessitates helping vulnerable individuals/groups cope with the adverse effects and reestablish their means of livelihood after climate disasters. Worth noting, combating climate change in the regions would require both local and extra-local efforts in a number of ways. For instance, future adaptations and mitigations to climate change vulnerability will have to be reflected in all regional polices [23].

Coping with climate change challenges will have to go hand in hand with major adjustments in various policies and legislations. For instance, the potential for utilization of renewable energies, namely, biomass, solar power, geothermal, wind energy, biogas, and natural gas would require significant regional governments' commitments in terms of policy adjustments and economic sacrifices. Successful harnessing of geothermal energy in Kenya, natural gas in Tanzania, and most of the renewable in Brazil could imply that proper policy adjustments could reduce power shortages in the regions. In recent years however, significant efforts in structuring climate change policies have been taken by nearly all regional governments. Although the efforts may be considered insufficient compared to the impacts, they do provide a fundamental framework to dealing with regional climate change challenges. These include the establishment of national bodies with full mandates on climate change issues and environment management at large and creation of several laws and legislations on environmental issues [27, 40]. Arguably, as a sign of worsening situation, most recent government policy documents in the regions do recognize climate change as an important impediment to their sustainable development. For instance, most climate change issues are notably defined in the regional National Adaptation Program of Action (NAPA) reports [40]. In summary, the regional bodies dealing with climate change requires an inclusion of how such projects and/or policies with potential negative impacts to the environment will be addressed before being accepted for implementation. The latter makes it mandatory for extensive Environmental Impact Assessment (EIA) to be carried out to such projects before they would be approved for implementation [27, 40]. However, care must be taken as some of the suggestions in the NAPA reports provide suggestion that might not work in the region. For example, some suggestions in the reports are considered too expensive in the region and require unavailable technology. Failures to fully involve local people have had bad experience in the region (particularly in Tanzania) where local people in the region objected some drought resistant crops on ground that they were tasteless and lacked market value [29]. The latter have resulted to poor adaptation to climate change impacts and left on agriculture a significant number of the individuals vulnerable. While some of the suggestion might work in the long run, real solutions to the challenges of climate change vulnerability would come from an inclusion of a wealth of local skills dealing with climate change and disaster management at large.

In appreciating the importance of forests in carbon sinking, forests have regionally been advocated as one of the most important gears to combat climate change. In accordance with the global move, regional efforts put a lot of emphasis on both reforestation and afforestation programs [23]. However, renewed efforts on forest management are needed as desertification has been increasing. In addition, special consideration needs to be taken on energy sector since a significant portion of regional energy balance is met from biomass energy [25]. Capitalization on the abundant potentials of renewable energy would reduce pressure on the natural forests and the amount of carbon emitted.

Alongside the suggestions above, it is worth noting that the regions lack necessary expertise and economic ability to deal with climate change and associated issues. Emphasis must thus be concentrated on training local scientists, planners, and policy makers to prepare them to deal with the worsening situation in the regions. In addition, future direction of climate change in EA and SA will have to be concentrated on land use change since major regional contribution to the GHGs comes via land use change and deforestation.

Furthermore, EA region has an abundant supply of carbon dioxide which requires purification only to be ready for industrial use. EA countries could capitalize on the natural supply of the gas and stop importation of the gas from other places. At present, most industries in Uganda, Tanzania, and Kenya still import carbon dioxide which is seen as a wasted regional opportunity both to control carbon and investment. As a potential investment, the Carbacid Company in Kenya has started mining the gas for commercial purposes. Thus, both regional and even neighboring countries could meet all their carbon needs from the region without requiring importation of the gas. Similar efforts need to be strengthened in other regional countries and potentially stop importation of the gas all together.

Other areas where strengthening can be done to reduce vulnerability to climate change include accurate information gathering and dissemination. The latter is important since most times when climate disasters strike many people have been caught unaware/unprepared and thus increased vulnerability. In addition to that, renewed emphasis on local capacity building and decision-making should be made central in helping vulnerable groups to adapt better to climate change impacts. Because of the poor resource base in the regions, it is very important for funds whether in the form of credit or otherwise to be available to vulnerable groups after climate change disasters. Such funds can help affected individuals or groups, to restock lost animals, buy farm inputs, and/or reestablish lost business or other means of livelihoods. The best way to ensure availability of funds to such groups/individual could be via rural credit mechanisms. Governments and other stakeholders should as well help rural credit mechanisms like pastoralists and/or cooperative unions get funds from financial institutions. This is important as regional studies have shown that individuals who have financial access like remittances from relatives generally recover faster and better from disasters.

Another potential area for future strengthening includes effective early warning systems on climate change disasters and effective information gathering and dissemination. Recent regional experiences have shown that climate change vulnerability is often worsened by failures to forecast potential climate disasters and poor communication between responsible authorities and the general population [40]. In the future, it would be very helpful to have a mechanism that would ensure such information is well forecasted and the general population is well prepared for the potential effects. Vis-a-vis to the above, it will be very helpful for regional bodies like meteorological departments and disaster management units to be equipped with advanced early warning systems for potential climate disasters and effective mechanisms to spread the necessary information. Albeit governments in both regions have taken certain steps in improving their disaster management units, further effort is still needed to improve them further by purchasing more accurate meteorological equipments and proper training of staff.

Finally, careful enforcement of environmental education in school curriculums may also prove to be a reliable means of reducing causes of climate change but most importantly help in regional adaptation and mitigation strategies. Because climate change and generally environmental degradation are presently appreciated to be developmental factors, it is crucial for regional education system to effectively prepare younger generations on environmental issues. Significant efforts have been made in recent years regarding inclusion of environmental aspects in school system and several environmental-related degree and nondegree programs are being offered in colleges [27]. Efforts can still be done to improve such curriculums to enable real solutions to local climate change–related challenges. Inclusions of environmental course in non-environmental programs in schools would as well help a larger part of the society become environmental sensitive.

Conclusion

In SA and EA, the negative climate change impacts are no longer potential threats but rather ongoing problems that have long been underestimated. Climate variability is already affecting many development projects and even threatens to undo some of the achievements made, including to some of the Millennium Development Goals (MDGs). Generally, the regional climate change vulnerability requires immediate actions as several sensitive ecosystems like the coastal resources, Eastern Arc Mountain forests, the Amazon forests; Mount Kenya, Mount Kilimanjaro, and the Andean Mountains are already affected. The negative impacts on agricultural systems, water resources, biodiversity, energy availability, infrastructures, and health issues are unmistakably clear and worsened by the fast growing population, wide spread poverty, among others. Today, ordinary people in the villages know their ways of making a living are threatened and are left with no option but to return to their indigenous survival skills. The status quo leaves the regions with potentials of being significant contributors of GHGs in the next decades via land degradation and especially deforestation of its fast shrinking forest resources so as to meet basic needs such as fuel wood. The use of poor often polluting technologies in the struggle for economic development and the desires to meet the needs of the fast growing population will also add to GHGs contribution in the future. As these regions near their peaks in terms of economic and industrial development, would mean a more net contribution in GHGs is likely because the regions will be consuming more energy, a trend that is already evident.

Most adaptations and mitigation options suggested by international bodies and which are largely reflected in the regional climate change strategies have local implementation difficulties. Since the economic base of the regions is among the world's least, implementations of such technical, expensive, and often unavailable options might prove to be difficult and could leave many people vulnerable to climate change impacts. Fortunately, the regions have rich indigenous skills and adaptation measures that require strengthening and inclusion into the regional vision for combating and/or living with climate variability. Thus, meaningful relief from climate change vulnerability will have to include existing livelihood strategies and especially recognition of the traditional resource management including on land that are well developed in the regions. However, local survival skills to the harsh conditions like droughts have in recent years been overstretched and feared not to work in the long term.

Unfortunately, governments and development planners within the regions were late to recognize that climate change was an issue of development and needed to be incorporated into all development projects. Climate change issues were for the long time not clearly reflected into the regional development plans and mistakenly treated as a separate entity resulting to bitter lessons. Because of the severity of the challenges of climate change to the delicate livelihood system in the regions, governments, private sector, and other stakeholders were forced to take decisive steps and recognize climate change to be an integral part of regional sustainable development.

Since major contributions to climate change causes come via land use change and naturals resources exploitation, land and natural resources like forests need to be central in dealing with climate change in the regions. Land and forest policies necessitate reexamining and better enforcing so as to control/reduce desertification, a trend of which has in recent years been significant in the regions.

Moreover, because both the courses and impacts recognize no regional boundaries, regions must move with the rest of the world in combating climate change. Regional governments, private sectors, individuals, and other stakeholders need to play their expected roles in both adaptation and mitigation measures to combat climate change. On the other hand, where as the international efforts do provide important generalizations regarding climate variability, they should try as much as possible to recognize special vulnerability in SA and EA where many of their frameworks dealing with the variability might not work as expected and should locally be assisted to deal with their problems in specific ways. While generalization simplifies things, specific issues in the regions, like over 70% of the population dependent on biomass on EA, need to be noted and treated in a special way.

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