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Impacts of environmental degradation and climate change on electricity generation in Malawi

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Abstract
Hydropower is an important energy source in Malawi because it provides almost all of the country's electricity generation capacity. This paper has reviewed the impacts of environmental degradation and climate change on hydropower generation in Malawi. Energy scenario and other issues that contribute towards the current state of environment have been discussed.
All of Malawi's hydropower stations are run-of-river schemes cascaded along the Shire River with an installed capacity of nearly 280 MW. The generation is impacted negatively by floods, siltation, droughts and aquatic weeds infestation. The way how these challenges are being exacerbated by the poor state of the environment, especially within the Shire River basin in particular is also discussed in the paper. Measures taken by the national electricity utility company on how to manage the impacts are discussed as well. The paper concludes that hydropower generation system in a highly environmental degraded area is difficult to manage both technically and economically. In the case of Malawi, diversifying to other energy sources of generating electricity is considered to be a viable option. Some mitigation measures concerning environment degradation and climate change challenges have been suggested in the paper.

Keywords: Malawi; Hydropower; Environment; Climate change; Electricity.

1. Introduction

1.1 General introduction

Hydropower is an enormous renewable energy resource, currently generating about 16% of world electricity [1]. Being renewable, hydroelectric power generation plays a role in global climate change mitigation as well as in enhancing air quality. Some developed countries have large shares of hydro electricity such as Norway (99%), Canada (59%) and Sweden (49%) [2]. It is also a dominant source of electricity generation in some developing countries like Brazil (84%) and Venezuela (74%) [2]. In Africa, despite having small levels of installed capacities, most countries in the continent (especially in sub-Saharan African region) have significant shares of hydropower in their electricity generation mix. In 2008, hydropower accounted for about 70% of the total electricity generated in the sub-Saharan African region, excluding South Africa [3]. In 2010, 32% of the African's electricity generation capacity was supplied from hydropower [4]. It is an important sustainable energy resource and can ensure national energy security. Through interconnection, hydropower can also foster regional development. However,

because hydropower depends on freshwater, its availability both in terms of quantity and quality has an effect on electricity generation and operation of the hydropower plant. In many places of the world, freshwater is currently under threat as a result of environmental degradation and climate change.
The global hydropower resource is huge. In 2009, the World Energy Council estimated that the global technical proven hydropower potential was 14,576 TWh/yr [5]. About 75% of the world technical proven hydropower potential is yet to be exploited; in Africa alone, 92% of technical proven potential is untapped [5]. While developing a hydropower project has its own challenges, it can be stated here that if the project is well planned, as the case in some countries, hydropower can be a solution to the global challenge of sustainable energy supply. Otherwise, hydropower projects can be difficult to operate and manage: technically, economically and socially. This can lead to reactions that hydropower projects are unsustainable. The experience of Malawi's electricity power sector, which depends solely on hydropower, will add to knowledge base on the challenges of hydropower generation that some developing countries in the tropics face, especially due to environmental degradation and climate change.
The next section describes briefly the geographical location, environment, economic and social circumstances of Malawi in order to set a base necessary for discussions on environmental and climate change impacts on hydropower generation.

1.2 Malawi's geographical, environmental and social-economic circumstances
Malawi is a sub-Saharan landlocked African country located south of the equator. It is bordered to the north and northeast by the United Republic of Tanzania; to the east, south, and southwest by the People's Republic of Mozambique; and to the west and northwest by the Republic of Zambia, as shown in Figure 1.

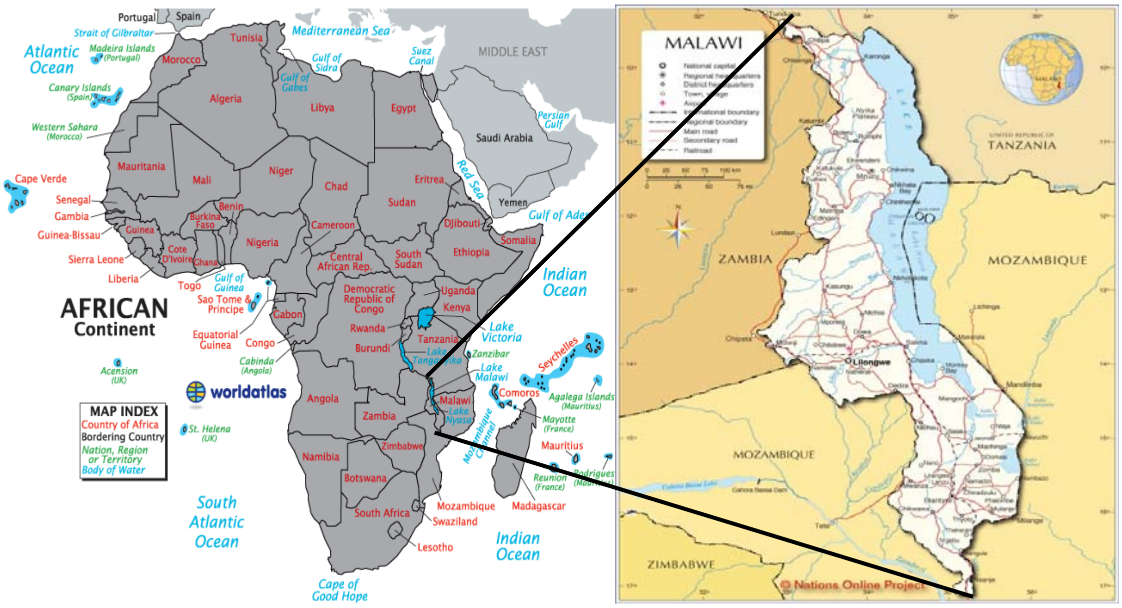

Figure 1. Map and position of Malawi with respected to Africa [6, 7]

The country is 901 kilometres long and 80 to 161 kilometres wide [8]. The total area is approximately 118,484 square kilometres of which 94,276 square kilometres is land [8]. The remaining area is mostly composed of Lake Malawi (known as Lake Nyasa in Tanzania), which is about 475 kilometres long. Malawi's most striking topographic feature is the Great Rift Valley, which runs the entire length of the country, passing through Lake Malawi in the Northern and Central Regions to the Shire Valley in the south. The lake is a fresh water body that lies in the Great Rift Valley and its main outlet is the Shire River, the biggest river in the country. Lake Malawi and the Shire River are the major sources of water for hydropower generation in Malawi.
Malawi has a tropical continental climate with maritime influences. Rainfall and temperature vary depending on altitude and proximity to the lake. From May to August, the weather is cool and dry. From September to November, the weather becomes hot. The rainy season begins in October or November and continues until April. However, the general weather pattern is changing. The climate is becoming

warmer, the duration and onset of seasons have changed, with onset rains coming in December and ending before April.

The question on whether Malawi is experiencing climate change or not can be answered through a scientific research by experts, and such a research study has not yet been carried out in the country. To the layman living in Malawi, if climate change is explained by changes in duration and onset of seasons, increased occurrence of extreme weather events such as floods, droughts and hailstorms, the layman will agree that indeed the country is undergoing climate change because this is the weather situation in the country. However, from numerous scientific studies conducted by renowned experts such as those from Intergovernmental Panel on Climate Change (IPCC), there is a lot of credible scientific evidence that the global climate is changing and negative impacts due to the change are happening [9]. Climate change is global and impacts may be global, regional and local. Thus a country, such as Malawi, may experience the impacts despite Malawi contributing insignificantly to the human induced causes of climate change. Climate change is stated to be caused by accumulation of gaseous emissions such as carbon dioxide, methane, nitrous oxide and carbon-fluorinated gases in the atmosphere. These gases are reported to be trapping heat in the atmosphere (global warming) like the way a greenhouse does, and because of this, they are also called ‘greenhouse gases’. The IPCC states the largest share of greenhouse gases comes from human induced activities such as energy generation and land use change [9].

Because of the increased frequency and magnitude of extreme weather events, and low adaptive capacity, Malawi is recognised as one of the vulnerable countries in Africa to negative impacts of global climate change [10]. The country has responded by developing the National Programs of Actions (NAPA) on how to adapt to impacts of climate change: the most vulnerable areas have been mapped [11]. Shire Valley, in which the country’s hydroelectric generating capacity is located, is one of the hot-spots mapped areas. The country has also instituted a department of National Disaster Management in the Office of the President and Cabinet, to respond to national disasters some of which are weather related.

Malawi is one the most densely populated in Africa. In 2011, the population was estimated to be around 15 million [12], giving an average population density of about 160 people per square kilometre of land. The increase in population, especially in the southern part of the country, is partly due to the influx of people who came to take refuge as a result of long civil war in Mozambique. Though the war has ended, some people have remained and mixed with the indigenous through marriages [13]. About 85% of the population live in rural areas where most of them are engaged in subsistence agriculture, relying on rain-fed farming [14], which imply that poor rains could bring national catastrophes. The GDP of the country in 2012 was USD 370 per capita [12] and basing on this, Malawi is considered as a low income country. The growth in GDP 2010 was 3.8 % [12]. The economy of Malawi is highly agro-based with about 30% of the GDP and 90% of export revenues coming from the agriculture sector [15].

Malawi, known as Nyasaland by then, was under British Protectorate by 1891. Between 1953 and 1963, the country was part of the Federal Government of Rhodesia and Nyasaland. The Federal Government comprised of Southern Rhodesia now Zimbabwe, Northern Rhodesia, now Zambia and Nyasaland, now Malawi. The Federal Government was governed by the British Government. In 1964, Nyasaland attained her independence and changed the name to Malawi. From 1964 to 1994, Malawi was a one party and an authoritarian state. From 1994 upto to date, Malawi is governed as a multiparty democratic country. Laws and regulations were relatively easier to enforce during the authoritarian period than this era of democracy.

This section may have provided some background concerning the current energy scenario and state of environment which is discussed in the following section.

1.3 Malawi’s energy and environment scenario

Malawi energy sector is relatively small in terms of generation and consumption of modern forms of energy. Table 1 shows some statistics of some modern energy consumption in the country in the year 2010 and 2011. In 2010, the net electricity consumption was 1.83 Billion Kilowatt-hours and the country ranked on position 139 in the world, a relative measure of how small the electricity the consumption and hence the economy is. The country does not produce any petroleum product but consumes a small quantity of only 9 thousand Barrel per day. Ethanol, as a liquid fuel is produced in the country and is blended with petrol to be used as a transport fuel. There are signs of presence of petroleum in Lake Malawi and currently exploration activities are underway.

Table 1. Energy statistics for Malawi [16]

Energy	Net Generation	Net Consumption	Year of data	World Ranking (based on consumption)
Electricity	1.97 Billion Kilowatt-hours	1.83 Billion Kilowatt-hours	2010	139
Coal	0.055 Million Short Tons	0.072 Million Short Tons	2010	98
Petroleum	0	9 Thousand Barrels per day	2011	128

In terms of energy consumption, the household sector is the dominant energy user and accounts for 83.2% of the national energy consumption [17]. This is followed by the industrial sector (11.9%); transport and service sectors consume 3.8% and 1.1% respectively [17]. As it is typical with many sub-Saharan African countries, the main source of energy supply in Malawi is traditional biomass, mainly in form of firewood and charcoal. In 2008, total biomass energy supply was estimated to be 8.92 million tonnes of wood equivalent (dry air) [17], this translates to about 700 kg of wood equivalent per capita in that year. Biomass is the most dominant energy in the household sector. About 98% of Malawi's households use firewood and charcoal for thermal services mainly cooking and heating [17]. Non-household applications of traditional biomass energy, apart from being used as tobacco curing fuel, include curing bricks in kilns (burnt bricks) and institutional cooking and heating (mainly in estates, secondary schools, prisons, hospitals and rural cottages). The main sources of traditional biomass energy (wood fuel) are natural forests in customary land.

In rural Malawi where the majority lives, firewood is simply the only type of fuel. Charcoal is the common fuel in urban areas, likely because charcoal can be packaged, has high energy content per unit volume and produces less soot than firewood. Even for those households in urban areas that use electricity for cooking and heating, the majority of them also use charcoal as stand-by fuel in the event of electricity unavailability. Further, some urban households in electrified homes choose to use charcoal on the basis that 'electricity is expensive'.

The rapid urbanisation of 6.3% per year [18] in Malawi contributes to high consumption of charcoal in urban areas. This scenario qualifies the fact that traditional biomass energy is so dominant in the country and that wood fuel is becoming scarce. Because of this, firewood and charcoal are traded and some people are earning their living through this trade. It common in Malawi to see stockpiles of firewood and charcoal bags displayed for sale along the road-sides and in market places, as shown in Figure 2. In 2005, Zingano estimated that about 8% of households in Malawi earned income from selling of charcoal [19]. A study in 2007 on charcoal industry in Malawi concluded that charcoal is a commodity with a large domestic market [20]. The estimated value of the industry was about 40 million US$, slightly less than the value for tea industry and accounted for about 0.5% of the country's GDP [20].

(a) (b)

Figure 2. (a) charcoal and (b) firewood for sale along the roads in Malawi [21]

Tobacco industry is one of the major consumers of firewood in Malawi. Firewood is needed for curing certain types of tobacco, as shown in Figure 3. Some types of tobacco are not fire cured, for example burley. But even for such types of tobacco that are not fire cured, poles for constructing barns and twigs for hanging and drying tobacco place extra demand on forest cover. Tobacco farmers are mandated by Land Act to set aside 10% of their farms for active forest cover, but this regulation is rarely adhered to and the enforcement mechanism if not even functional [13]. The result is the continued unsustainable harvesting of trees leading to uncontrollable loss of forest cover.

Figure 3. Firewood for curing tobacco [13]

Tobacco farming is the major cause for loss of forest cover in the Central Region (a tobacco growing region) and some parts of Rumphi and Mzimba in the Northern Region [13]. In 1980, about 40% of wood consumed in the country was used for tobacco curing mainly as a result of unprecedented expansion of tobacco curing as a result of increased demand following and favourable market conditions of tobacco during that period [13]. Any interventions to minimise loss of forest cover in the tobacco industry must be executed with care so that tobacco production is not threatened. This is so because tobacco is the single crop that makes the largest portion of mechanised exports in the country. It contributes about 13% of the GDP and 23% of Malawi's tax base [22]. Unless the country finds an alternative cash crop (or others sources of foreign exchange) or the anti-smoking campaign successfully manages to discourage tobacco production, reliance on tobacco will continue to be one of the major causes of deforestation in Malawi.

Brick curing industry is next to tobacco in terms of causing damage to forest cover. Nearly all burnt bricks (as compared to concrete blocks in other countries) for construction in Malawi are produced in scove kilns (Figure 4) and the process is inefficient as it requires a lot of wood fuel to cure a unit quantity of bricks [19]. In the scove kilns, unburnt bricks are stacked together, leaving spaces for provision of firewood and then are daubed with clay to reduce the loss of heat during the curing process (Figure 4). Burnt bricks are the most common construction materials for permanent buildings and other structures in Malawi. Just like charcoal, selling of burnt bricks is one of the livelihoods for people living near cities and other urban areas. As the country develops, the market for burnt bricks is relatively huge; in construction companies and individual building projects. Unless alternative building material in place of burnt brick is found, burnt brick industry has ability to destroy Malawi's forest cover significantly. Already, in some urban areas of Blantyre and Lilongwe, some people have started using mango trees and trees from graveyards to burn the bricks because trees in surrounding areas have been depleted [13]. Mango trees are most of the times preserved for fruits and trees from graveyards are normally not cut down on cultural reasons.

Figure 4. Brick curing kilns in Malawi [21]

Deforestation is one of the major causes of environmental degradation in Malawi. Apart from the already discussed unsustainable biomass energy supply, other factors are population growth, agriculture expansion and urbanisation.

1.4 Malawi government policy interventions against deforestation

The Government of Malawi is aware of the environmental impacts emanating from continued dependence on traditional biomass fuel. The overarching national development strategy paper for the period 2011-2016 "The Malawi Growth and Development Strategy II" in the theme number 1 has included issues of natural resources and environmental management [18]. Further, the new Constitution of Malawi, adopted in 1995, calls for sustainable management of environment and natural resources. Furthermore, relevant departments; namely Department of Energy Affairs (DoEA), Environmental Affairs Department (EAD) and Forestry Department (FD) are governed by department-based policies and legal instruments concerning managing the environment - the National Energy Policy of 2000 (revised in 2003), National Environment Policy of 2000 and National Forestry Policy of 1996. All these policies have objectives and strategies concerning reducing dependency of wood-fuel as source of energy in Malawi. The departments were/are also involved in programs aiming at reducing deforestation; for example, the DoEA have the following programs: i) Promotion of Alternative Energy Program (PAESP), looking at alternative sources of energy especially for cooking and heating; ii) National Sustainable and Renewable Energy Program (NASREP), which has been looking at promoting renewable energy in general to contribute significantly to the energy mix so at to reduce depends on biomass, iii) Barrier Removal to Renewable Energy in Malawi (BARREM) which was concerned with identifying and removing barriers towards the uptake of renewable energy in Malawi and iv) Malawi Rural Electrification Program (MAREP) which is geared at supplying electricity to rural towns and growth centres.

In the Department of Forestry, the programs aimed at conserving forests include the following [13]: i) Tree Planting and Management for Carbon Sequestration and other ecosystem Services, iii) Forest replanting and tree nursery projects, iv) Sustainable Management of Indigenous Forests, and v) Wood energy plantation. There is also a period set aside by the Malawi Government for national tree planting, where every Malawian is urged to plant at least a tree. However, despite the presence of policies and programmes, there are still critical challenges of deforestation [13]. This shows policy failure in managing forests in the country.

Deforestation and environmental degradation are some of major problems in the country. Even legal ways of curbing deforestation seem ineffective. The Land Policy regulation that mandates tobacco estates to conserve at least 10% of the estates land for active forest cover is not adhered to often times, as already stated. In protected forest reserves, deforestation is prohibited by law. It is currently very difficult to enforce this law and some surrounding communities have openly encroached into the protected forest reserves and illegally harvest trees despite presence of forests guards as the case with Liwonde Forest Reserve and Mwabvi game reserve in the southern part of the country [13]. The protected Chikangawa Plantation, which is the largest man-made plantation in the country and originally accounted for nearly 60% of all forest reserves in Malawi [23], is currently undergoing an uncontrollable and unsustainable deforestation. The Chikangawa trees are being harvested mainly for timber which is exported and there are very little reforestation activities in the forest [24].

In customary forests which account for about 50% of the total forest cover in the country [25], deforestation is left unchecked because the current regulation allows indigenous to harvest trees in such forest for domestic purposes and not for sale. Even if such trees are harvested for sale, there is no enforcement of the legal provision. In Malawi, charcoal for trade can be produced only by licensed businesses; the licence is obtained from the Department of Energy Affairs. However, the situation on the ground is different; there is laxity in enforcement of the law against illegal charcoal trade. Charcoal is traded freely without licences by small scale business people. As already stated, the sight of heaps of charcoal bags for sale along road-sides and in market places is common in the country, indicating seriousness in the level of deforestation in the country. Clearly, as the case with policy interventions, there is also enforcement failure in preventing deforestation in Malawi.

So what should the Malawi Government and other stakeholders do to prevent the current state of deforestation and environmental degradation? Despite presence of policies and legal frameworks the problem of deforestation is still continuing, as already stated. Between 1990 and 2010, forest cover in Malawi is reported to have declined from 41% to 34% [26]. What factors are responsible for policy and

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regulatory failure? Have they got to do with relatively high poverty levels and limited sources of livelihoods for most of the Malawians? While these questions can be answered through a research, one observation is clear. Deforestation and the resulting environmental degradation negatively impact the economy of the Malawi. One of the economic sectors that have been negatively impacted is the electricity sector as will be discussed later on in the paper. The electricity sector is described first then followed by the impacts of environmental degradation and climate change on electricity generation.

1.5 Malawi's electricity sector

As it has already been stated, Malawi's energy sector is predominantly traditional biomass-based. The national energy mix for 2000 and 2011 show some minor improvement on relieving some level of overdependence of biomass energy. As shown in Figure 5, dependency on biomass energy mix has slightly been reduced from 93% in 2000 to 80% in 2011, as a result of some increases in the mix of modern forms of energy such as electricity, coal, liquid fuel and gas. Despite the improvement, electricity sub-sector contributes very little in the energy mix, contributing less than 10% of the total energy supply.

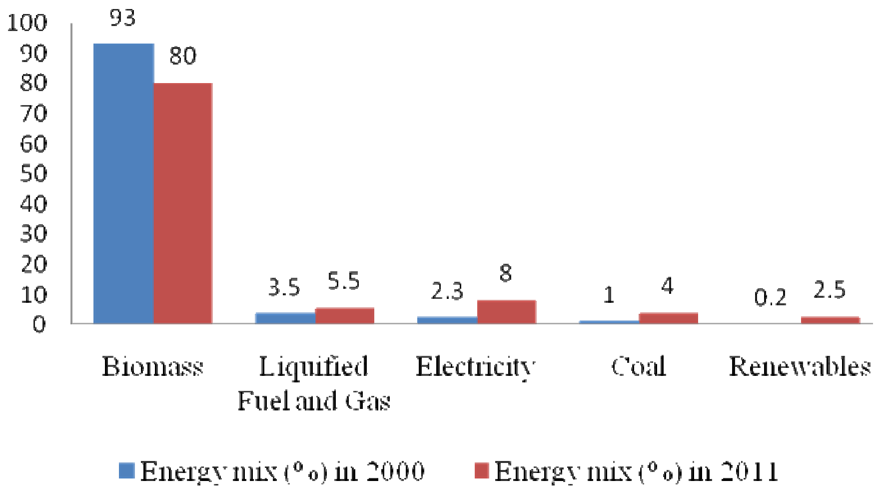

Figure 5. Malawi's energy mix in 2000 and 2011 [17, 27]

The national electricity access level is between 7 to 8%, rural electricity and urban access levels being about 1% and 20 % respectively [14]. The level of about 1% for rural electricity access is reported to have remained static over the last 16 years [14]. The annual national electricity consumption is 111 kWh per capita per annum [14], which is obviously concentrated in urban areas. These indicators are typical of a low developed country.

Despite the presence of liberalised national energy policy, the whole amount of grid-based electricity capacity is generated, transmitted and distributed by the Electricity Supply Commission of Malawi (ESCOM), the only power utility company in the country. ESCOM Limited is a public utility company. The grid-based electricity installed capacity for the whole country is 302.5 MW; this includes the 20 MW thermal electric plants (diesel electric-generators). The installed thermal electric power plants are currently not available and the country gets grid-based electricity from hydroelectric power stations only. Because of this, sometimes the total installed capacity for the country is quoted as 282.5MW. If the thermal-electric power plants are included, then, about 93% of the installed capacity is sourced from hydroelectric power stations and 7% is sourced from thermal electric power stations. Of the 282.5 MW installed capacity, 278 MW (98%) is sourced from power stations located in a cascaded form along the Shire River located in the southern part of the country (Shire Valley); the remaining 4.5 MW (2%) is sourced from three mini-hydroelectric stations installed on Wovwe River in the northern part of the country. The number of installed hydroelectric power machines and their installed capacities are shown in Table 2.

All of the developed hydroelectric power schemes are run-of-the-river types. The power stations located long the Shire River use Lake Malawi as a natural reservoir. The flow of water for power generation in the Shire River is controlled at Liwonde Barrage (also known as Kamuzu Barrage) at Zalewa (refer to Figure 6). The profile of the Shire River and the location of hydropower stations are shown in Figure 6.

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Table 2. Installed hydroelectric power plants in Malawi [28]

Plant	River	Installed capacity (MW) = (number of Plants) x (installed capacity of the plant)	Cumulative installed capacity	Year Installed
Nkula A	Shire	3 x 8	24	1966
Tedzani I	Shire	2 x 10	44	1973
Tedzani II	Shire	2 x 10	64	1977
Nkula B (I)	Shire	3 x 20	124	1980
Nkula B (II)	Shire	1 x 20	144	1982
Nkula B (III)	Shire	1 x 20	164	1986
Wovwe	Wovwe	3 x 1.5	168.5	1995
Tedzani III	Shire	2 x 25	218.5	1996
Kapichira	Shire	2 x 32	**282.5**	2000

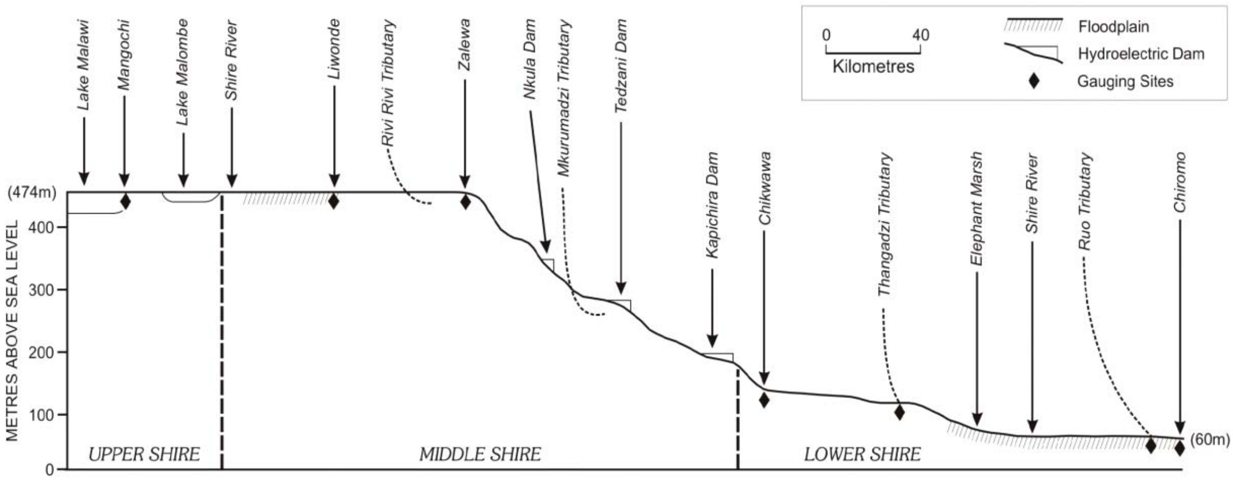

Figure 6. Shire River profile from Lake Malawi outlet up to the flood plains of the Lower Shire valley showing the upper, middle and lower reach sections, hydroelectric dams and flood plain [29]

By any standard, the generating capacity of about 282 MW against a population of 15 million people is too small for a country. Understandably, demand is higher than supply and ESCOM is not able to connect electricity to all customers who have applied. Some businesses and households have resorted to generating self electricity using portable diesel electric generators (gen-sets). In 2010, the Malawi Energy Regulatory Authority estimated a generation capacity of over 60 MW from these small gen-sets [30]. The future electricity demand (without factoring in demand for the future industries) for 2015 and 2020 is estimated to be 478 MW and 757 MW respectively [31]. Major industrial investments especially in the mining sector are failing to start because of shortage of electricity [31].

Malawi has a significant amount of proven hydropower potential (untapped) which if exploited enough, could alleviate this shortage of electricity. The untapped hydropower technical proven potential for the country for large scale electricity generation is about 2,000 MW [14]. Table 3 and Figure 7 show locations and capacities of the untapped hydropower sites. The exercise of mapping hydropower potential sites was done during the conceptual stage of the Millennium Challenge Corporation Project in the Energy Sector where potential energy resources and the associated costs to develop them were identified for a possible public-private partnership initiative [14]. Information in Table 3 on estimated cost is for indicative purposes. The estimated development cost shows that hydropower sites on Low Fufu, Kholombidzo, Mpatamanga and High Fufu have relatively lower development cost per unit electricity generated than other potential sites. Internationally, typical costs of electricity produced by a conventional large scale hydropower plants ranges from 1 to 4 USc/kWh [32].

Table 3. Untapped hydropower potential sites and the estimated development costs [14]

River	Site	Estimated Capacity (MW)	Estimated development cost (USc/kWh)
Songwe	Manolo	60-130	4.2 – 4.8
	Proposed multipurpose Dam	300	-
Wovwe	Expansion of existing minihydro site	15 (extra)	-
South Rukuru	Low Fufu	75 - 140	2.3 – 2.4
	Low Fufu Transfer	90 - 180	2.4 - 2.5
	High Fufu	90 - 175	3.7 – 5.4
	Henga Valley	20 - 40	8.7 – 9.3
	Rumphi (Pumped Storage system)	3 – 13	12.3 – 21.8
Dwambazi	Chimgonda	20 – 50	7.2 – 9.8
Dwangwa	Vipya sites	50	-
Bua	Chizuma	25 - 50	7.1 – 8.5
	Chasombo	25 - 50	9.5 – 11.8
	Malenga	30 - 60	17 – 29.1
	Mbongozi	25 – 50	14.1 – 17.3
Shire	Kholombidzo	140 - 280	2.7 – 2.9
	Mpatamanga	135 - 300	2.3 – 2.9
Ruo	Zoa Falls	20 - 45	4.6 – 5.8
Total untapped potential		**Up to 1,928 MW**	

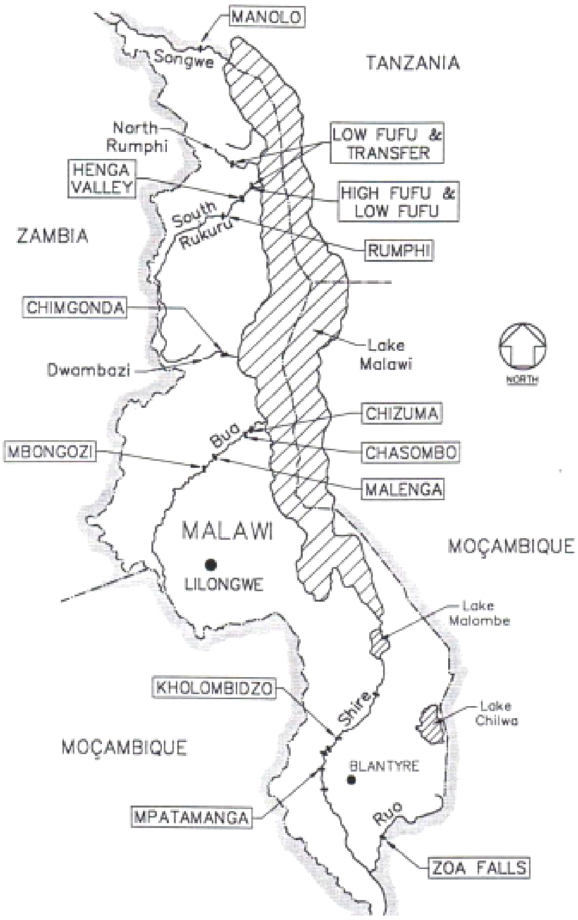

Figure 7. Map of Malawi Showing Untapped Hydropower sites [33]

Hydroelectric power technology is a tried and proven one and with such a relatively large unexploited potential, it would make sense for Malawi to consider further developing the untapped hydropower sites for electricity generation. The government's programs on expansion of hydroelectric power include the following planned projects:

1. The Government of Malawi, through fuel levy, plans to increase electricity generation by adding 64MW of installed capacity through the Kapichira II project which is expected to be which is reported completed by 2014 [31]. This will increase the total installed capacity to 347 MW.
2. The Government of Malawi plans to purchase about 300 MW from Mozambique (Carbora-Bassa Hydroelectric Power Station) by means of grid interconnection. The government passed the Interconnection Bill in 2007 and power purchased from Mozambique was expected to be part of the Malawi grid system by 2011 [31]. Currently (in 2012), discussions on the modalities of this grid interconnection are still reported to be underway.
3. The Government of Malawi in collaboration with the African Development Bank (ADB) and the Government of Tanzania plans to construct multipurpose dam along the Songwe River Basin. A total an installed capacity of 342MW is planned to be generated from the dam. This is a ten year project to be financed by the African Development Bank (ADB) [31].
4. The Government of Malawi plans to develop Low Fufu hydropower site on South Rukuru River in the northern part of the country by 2016. The ADB has agreed to fund the feasibility studies on the site. This project will add extra 144MW into the grid system [31].
5. Rehabilitation of the existing hydroelectric power plants along the Shire River to improve on their generation efficiency and availability. This will be achieved through Millennium Challenge Corporation grant as explained already.

As already stated in the introduction section, hydropower depends on the quality and quantity of fresh water. Water quality in most of the Malawian rivers is affected by siltation due to environmental degradation in the catchments areas. As the global warming manifests itself, Malawi is not spared from its impacts. Some rivers are no longer perennial and even the trend in water level in Lake Malawi is showing a reduction due to reduction in runoff in the catchment areas and increased rates of surface water evaporation.

Adaptation to impacts of climate change exacerbates the problem of environmental degradation in the country. For example, people who depend on subsistence agriculture for livelihood are vulnerable to droughts. As a coping mechanism against droughts (causing low food production), people look for alternative means of livelihoods. They cut down trees in the protected catchment areas of some important rivers for charcoal and firewood for sell in urban areas. They also practice unsustainable small scale irrigation in protected wetlands of the river banks during dry season. These practices accelerate sedimentation of the river especially during the rainy season. The challenges of droughts are acute in the Shire River Basin. Therefore, the hydropower expansion programs along the Shire River and other rivers (Figure 7) must be well planned to make sure that appropriate mitigation measures against the environmental degradation are well incorporated in the designs to ensure sustainable hydropower systems.

The following section discusses the impacts of environmental degradation in the Shire River Basin and climate change on the electricity generation.

2. Environmental and climate change impacts on hydropower generation

2.1 Droughts

The amount of water for power generation in the hydroelectric power stations located in the Shire River depends; to a larger extent on the water level in the Lake Malawi. Frequent droughts in the country and increased rate of evaporative loss in the lake have reduced the water level, and hence the flow in the Shire River. The hydropower systems in the Shire River are designed for a firm water flow of 170 m/s^3 [34] and flow below this amount reduces the generating capacity. It is recorded that due to frequency of droughts during the period of 1915 to 1935, the lake level was so low such that there was completely no outflow into the Shire River [34]. Of course, by that time there was no any hydropower plant installed in the river, otherwise the impacts to electricity generation would have been catastrophic. It is due to these changes in water level in Lake Malawi that Liwonde Barrage was constructed in 1965 to control water flow for electricity generation downstream of the Shire River [14].

During the period of hydropower installations in the river (starting from 1966), droughts have negatively affected electricity generation. The droughts which occurred during 1992 to 1998 period reduced water levels in Lake Malawi and affected electricity generation in the Shire River [34]. In fact in 1992, the outflow from the lake measured at Liwonde Barrage was 130 m^3/s, far below the required design flow of 170 m^3/s for power production [11]. Again, in 2004 and 2005, the water flow in the Shire River was reduced affecting hydroelectric power generation and other economic sectors following droughts in the Shire River Basin [35].

Furthermore, studies on impacts of climate change (using Global Circulation Models) on near future hydropower generation potential for Malawi indicate a reduction trend [36]. Therefore, adaptation measures are needed for the current hydropower installations and the planned ones. For the current installations, the Government of Malawi proposes installation of a feed-pump system to pump water from Lake Malawi into Shire River at the mouth of the river (at Samama in Mangochi) so as to maintain the 170 m^3/s flow for required for power generation downstream in case the lake levels recede to levels that can cause extremely low flow in the river. The proposed project is part of the Integrated Water Resources Development Scheme for Lake Malawi and Shire River system [37]. ESCOM plans to diversify power generation to other sources of energy such as coal, bagasse and uranium [28]. The basis for choosing these fuels is their availability in the country. A sustainably operated coal-fired thermal-electric power plant of 300 MW capacity has been proposed according to the amount of current proven coal reserves in the country [28]. While a nuclear energy operated thermal-electric power station may be a long term plan, electricity production using coal is feasible and the coal-fired electricity project is already been included in the Electricity Generation Master Plan of ESCOM.

2.2 Floods

In Malawi, the number of disaster events as a result of floods keeps on increasing (as shown in Figure 8). Most areas where incidences of flooding occur are along the plains and valleys along Lake Malawi and Shire River Basin. The levels of intensity and frequency of flooding in the Shire River Basin are reported to be more than any other places in the country [38]. The floods are in most of the cases due to high rainfall intensity received in the catchment areas within a relatively short duration of time and in some cases, rising levels of Lake Malawi. As stated in the NAPA [11], and Malawi Environmental Outlook Report of 2010, incidence of flooding is aggravated by climate change and environmental degradation in the country.

In the Shire River Basin, the floods cause significant devastation to not only to hydropower infrastructure, but to bridges, roads and human settlements. The rising of Lake Malawi levels in the period of 1978 to 1986 caused severe flooding along the lake shore and Shire River seriously affecting electricity generation [40]. In December 2001, Tedzani power stations I & II went completely out of service due to damage to the intake screens caused by debris and water force during a flood event. This resulted in the loss of 40 MW of capacity from the grid. The two power stations have been brought back into operation in 2008. The stations took such a long period of time to be brought back into operation because ESCOM was sourcing funds amounting to almost US$ 22 million to rehabilitate the plants [28]. Again, in March 2003, Nkula B Hydroelectric Power Plant, which has an installed capacity of 100 MW, and is Malawi's largest hydropower plant, was completely flooded, due to a faulty penstock valve during a flood event. It took about 5 months to finish rehabilitation of the power station [28]. Flooding along the Shire River is the major challenge of hydropower generation in the country with serious national economic consequences.

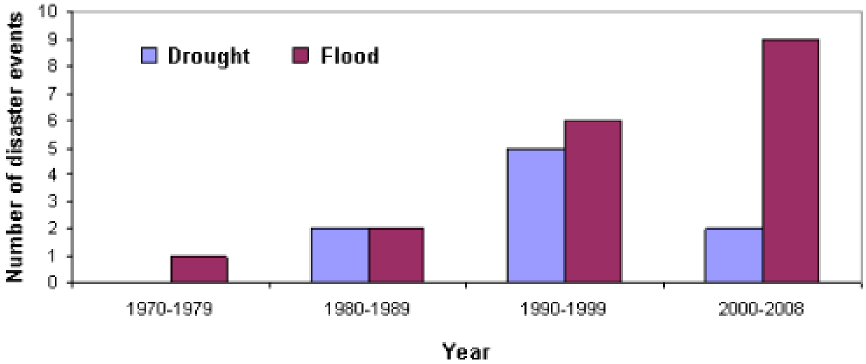

Figure 8. Evidence on the increasing frequency of floods and droughts in Malawi [39]

2.3 Siltation

Shire River catchment area is one of the areas in Malawi that suffer from severe land degradation and soil erosion. This is due to high population density, unsustainable agriculture practices, limited livelihoods and climate change as already discussed. The resulting siltation in the Shire River affects water quality for hydroelectric power generation. ESCOM is currently facing challenges not only of removing sediments from the intake reservoirs, but also of removing the silt suspended in water before the water is administered into the turbines for power generation. The sedimentation of the Nkula reservoir has also reduced its water storage for peak power generation. In 1996, the challenge of sedimentation at Nkula reservoir became so acute such that only 30% of the live storage was available for power generation [28]. This resulted in inability to meet peaking requirements resulting into countrywide load shedding. Significant amount of financial resources was spent to recover some of the lost storage especially in procuring a dredger and carrying out dredging operations [28]. In July 2003, Kapichira Hydroelectric Power Station was almost rendered out of service when its intake reservoir became silted up to 70% (Figure 9). The repairs to the reservoir and its reclamation took about 3 months and at considerable capital expenditure [28]. The silt in water has increases the rate of turbine erosion thereby reducing the design life of the plant. Increased rate of turbine maintenance due to turbine erosion has increased the maintenance budget at ESCOM [28].

Figure 9. Kapichira reservoir siltation up to 70% siltation in 2003 [28]

2.4 Aquatic weeds

Shire River system, especially the upper section (including Lake Malombe) is infested with aquatic weeds which have caused problems that affect peoples' livelihood (such as fishing) as well as hydropower generation. The most common types of water weeds in the Shire River are water hyacinth (*Eichhornia crassipes*), red water fern (*Salvinia molesta*), water lettuce (*Pistia stratiotes*) and elephant grass [41]. The most notorious of them is the water hyacinth. Water hyacinth floats on the water and it can survive in mud, enabling it to survive even during the dry seasons [42]. Aquatic weeds cover the surface of open water and increase water loss due to increased rate of evapo-transpiration. They also reduce the water flow velocity thereby contributing to sedimentation of the river. The floating aquatic weeds are the major debris in water which must be removed from the water at intakes before it is conveyed to the turbine for power generation. The rate of removal of aquatic weeds from water at the intakes can be overwhelmed by the arrival and accumulation of the weeds. Accumulation of weeds at the intakes can cause damage to the intake screens. Accumulation of the weeds at intake also causes vacuum pressure in the water conveyance system from intake to the turbine. The vacuum pressure can cause the turbines to trip as well as cause the conveyance system to collapse. From 2001, hydropower generation in the country has been disrupted almost every year in the rainy season due to aquatic weeds [28]. Repair of damaged parts such as screens and valves and removal of weeds repairs increase the generation operational costs.

Since most of the aquatic weeds originate from the upper Shire, ESCOM operates an aquatic weed management program. Weeds are trapped and removed from the river mechanically at Liwonde Barrage (refer to Figure 10 (a)). But when the weeds accumulate, they are flushed down downstream of the river where they cause problems to the hydropower stations. Figure 10 (b and c) show a damaged screen as a result of aquatic weeds at Tedzani Hydropower Station. The costs of managing weeds are very high. For example, in 2009, nearly 370,000 US$ was spent on managing weeds at Liwonde Barrage only [43], not considering costs due to weed removal at the intakes.

(a) (b) (c)

Figure 10. (a) Mechanized Weed harvesting using Grab Crane at Liwonde Barrage, (b) Damanged course screen at Tedzani Power Station and (c) Damaged fine screens at Tedzani Falls [41]

As reviewed in this section of the paper, the impacts of environmental degradation and climate change on hydropower generation in Malawi are therefore great. Management of siltation, aquatic weed infestation and machine repair increases operational costs of ESCOM. The public utility company also losses in revenue collection as a result of reduced amount of electricity generated. For example, in 2009, Government of Malawi and ESCOM spent nearly US$ 1 million on silt and weed management on the three hydroelectric power stations [43]. In the same year, 2009, the total revenue lost as a result of machine unavailability at all the three stations was estimated to be close to US$ 1.2 million [43]. For a generating system of 278 MW installed capacity (excluding Wovwe Small Hydropower Plant), this translates to a direct loss of US$ 3.6 /kW of installed capacity as a result of environmental degradation as well as an indirect loss of US$ 4.3/kW of installed capacity through loss of revenue collection. Such expenditures would have been used for other projects, such as power expansion projects.

Reduction of generation capacity and electricity interruptions has negative consequences to the economy of the country. For example, in 2010, economic loss due power outages was around 2 % of Malawi's GDP [44]. Management of the environment in the catchment area is therefore a mandate, and since ESCOM is a public company, the government should take extra measures to ensure that environmental degradation is prevented in the catchment area of Shire River.

3. Conclusion

From this review paper, it can be concluded that Malawi's hydropower generation is impacted negatively by environmental degradation and climate change. The major contributing factors towards environmental degradation are overdependence on traditional biomass energy, limited sources of livelihood and unsustainable agricultural practices. Floods, siltation and aquatic weed infestation are the main environmental challenges facing hydropower generation. These challenges have affected economic performance of electricity utility company and the country at large.

It seems, from this paper that hydropower generation system in a highly environmentally degraded area is extremely difficult to manage both technically and economically. It is therefore, important for Malawi to diversify electricity generation sources, other than relying solely on hydropower stations located in the Shire River. For the current installed hydropower systems, there is need to find long term environmental degradation mitigation measures in the Shire River catchment area to ensure sustainable operation of the power systems. There is also need for flood control systems in the Shire River. One possible example of a flood control measure is upgrading of the current Liwonde Barrage to enhance its capacity and efficiency in controlling Lake Malawi water levels. Since all the hydropower stations are run-of-river systems, upgrading the current storage facilities (for peak purposes) to large scale reservoirs may help to mitigate floods and transform the plants into storage hydropower schemes. There is also need to consider inclusive environmental management programs where surrounding communities take active roles.

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