Chapter 2
Energy Resources in East Africa

2.1 Introductory Remarks

When talking about East Africa, traditionally this refers to the states of Kenya, Uganda and Tanzania with a combined population of over 120 million people in 2014. The three countries have a long history of association under the umbrella body known as the East African Community. In recent times, Rwanda and Burundi also joined the Community. Most of the discussions in this chapter focus on the traditional East African states of Kenya, Uganda and Tanzania, which have a lot in common in terms of their peoples and cultures. The two main dominant ethnic groups are Bantu and the wider Nilotic groups. Both groups are present in all the three states and have, over the years, interacted almost freely across the borders in line with the African traditional commitment to extended family ties including inter-marriage and many years of historical trade ties. After the Second World War, a single colonial power ruled the three states as separate entities but the ties between them were so entrenched that when these countries became independent, they readily formed the East African Community which was expected to eventually evolve into one political federation. Under the Community, several important services were jointly managed and coordinated by the East African Assembly whose headquarters had been carefully planned and built at Arusha, Tanzania, complete with all the necessary secretariat facilities including conference facilities and accommodation for staff in anticipation of an eventual political union. However this expectation was not realized and, instead, the community disintegrated in 1977 but was later reconstituted and expanded to include Rwanda and Burundi as will be discussed later. Such changes in institutional arrangements and internal political instability as well as deliberately designed external factors have adversely affected the development of the energy sector in East Africa. Further, the political leaderships in the developing countries, in general, do not seem to understand the crucial role played by energy in all development processes. Thus, the development of

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energy resources is low-keyed in these countries and its position as the driving force in national development is taken for granted.

In East Africa, like in many other developing countries, energy supply and resources are divided into two main groups namely commercial and non-commercial (informal) energy resources. The commercial energies are electricity and petroleum-based fuels and these are the forms of energy that usually draw the attention of national governments because their availability and distribution have strong impact on the economy and directly affect the rich and the powerful members of the society. The other group of non-commercial energies includes biomass materials such as wood, charcoal, plant and animal wastes. Although some of these especially charcoal and, to a lesser extent, wood, are today available in the local markets, they are still largely obtained free of charge by the users. Charcoal however has gradually moved from household production to dispersed commercial production and is now established as an income generation activity. It is nevertheless considered as a non-commercial energy because its production and marketing is still done on an ad hoc manner by individuals who may not necessarily be professional charcoal producers and who often switch from charcoal trade to other activities. In terms of the total energy consumption in East Africa, non-commercial energies contribute well over 80 % of the total energy. Commercial energies on which the governments spend large portions of their GDP contribute less than 20 % of the total requirement. Non-commercial energies are not clean and pose a lot of health hazards to the users in addition to environmental degradation associated with their use. The responsibility of obtaining non-commercial energies is traditionally left in the hands of women and girls and generally it consumes a lot of time, and this has severely limited the participation of women and girls in other economic activities including education, making them the automatic disadvantaged groups in the society. One of the desires of the modern energy policy is to make people shift from traditional non-commercial energy resources to more modern, clean and convenient energy sources such as electricity and LPG for domestic applications. Experience in East Africa has however indicated that this is wishful thinking and will remain so unless deliberate efforts and even national sacrifices are made to give people clean energy at affordable cost. But this also requires that the quality of housing will have to be significantly improved in the rural areas. Many international studies have concluded that for many years to come, a large proportion of people will continue to rely on biomass energy on account of its availability and possibility of regeneration. The economic development of Kenya, for example, is considered to be way ahead of those of Tanzania and Uganda and yet the reliance on biomass fuel continues to steadily increase in Kenya. Another aspect that also does not seem to worry the governments is that biomass resources are obtained from standing stocks instead of from yields. This has been going on for a long time and already hardships associated with its shortages are experienced in many parts of the rural areas. The shortage also has its own implications on land quality and ultimately on the welfare of the people. So it is important to accelerate transition to modern fuels as this would reduce pressure on the land and forestry and hence make it possible to sustain good soil quality for food production and general welfare of the people in terms of poverty reduction. Although some studies have suggested a steady and gradual upgrading of energy use, for example, from biomass to Kerosene to LPG and electricity, the rule cannot be strictly applied in all situations. Energy upgrading may not be achieved through this ladder-climbing model because its optimum use for a particular user is more of the proper mix rather that quality differences.

In all the East African states, the desire in the energy sector is to increase accessibility of reasonably priced high quality energy to the people on a sustainable basis. The governments recognize that the success of socio-economic and industrial developments will, to a large extent, depend on the performance of the energy sector particularly the development and diversification of energy sources. Although the role of energy in development has always been crucial, very little support has been given to energy initiatives and therefore there are numerous problems that will have to be addressed in order to have a meaningful foundation for energy supply in the region. The major challenge is how to deal with the weak generation, transmission and distribution infrastructure and the policies, which have inhibited investments in the energy sector. These weaknesses and the high cost of energy are viewed as hostile conditions not just for investment but also for ordinary power consumers and, as a result, there is very low per capita power consumption in the region. Most people are forced to use own crude sources of energy such as biomass-based fuels. In view of these factors, energy resources that are locally available in the region such as biomass, solar, wind and small hydro schemes will be discussed in details including their conversion technologies. This is done in recognition of the fact that future self-sufficiency in energy for the region may significantly depend on these renewable resources and the fact that there is a general global shift from fossil-based fuel to renewable energies. The other resources will also be discussed but without the detailed conversion technologies.

2.2 Background Facts of East Africa

To be able to clearly understand the energy situation in East Africa, it is important to know certain basic important facts regarding the geography, available natural resources and the economic activities in the region. East Africa was initially known to comprise of four states: Kenya, Uganda, Tanganyika and Zanzibar. The union of Tanganyika and Zanzibar in 1964 into what is now known as the United Republic of Tanzania reduced the number of East African states to three. Both Kenya and Tanzania have Indian Ocean coastline while Uganda is landlocked. Lake Victoria, the world's second largest fresh water lake, lies at the common border of the three states and so control of the lake's resources especially fisheries has often caused some conflict. Luckily the situation has never reached a level that would warrant international mediation. Prior to 1961, all the three states were under control and administration of the United Kingdom. Tanganyika was initially controlled by Germany but, after the Second World War, the United Nations mandated the United

Kingdom to administer it. Thus all the three East African states got their independence at different times from United Kingdom.

Around the time of independence, the natives of the region had a strong desire to form one federal state of East Africa but this did not happen partly due to the fact that independence was granted at different times, allowing political leaders of each state to develop their own selfish ambitions. However, the common heritage and close socio-economic relationships of the natives persuaded the leaders to establish an East African Community with its headquarters in Arusha, Tanzania. The structure of the Community had some very weak elements of federalism in which some services such as posts, telecommunication, power generation, transmission and distribution, harbours, railways, universities, high school examination system, etc., were jointly controlled by the three states through East African Community. The more sensitive areas like security, economic management, political leadership and crucial executive powers were left in the hands of individual states. The Community was therefore too weak and vulnerable to stand the test of time. It was finally disbanded in 1977 when the Ugandan dictator, Idi Amin could not get along with the other two leaders particularly with Julius Nyerere of Tanzania.

Kenya and Tanzania have been relatively peaceful and stable politically but there was some hostility between them due to the differences in political ideologies. Uganda, on the other hand, has had some very turbulent moments. The dictatorial regime of Idi Amin claimed the lives of about 300,000 people between 1971 and 1979. The gorilla wars and the human rights abuses under other leaders were responsible for the deaths of close to another 100,000 people. Uganda returned to relatively peaceful path of development in 1986 when Yoweri Kaguta Museveni seized power.

In November 1999, the three states, with a clearer understanding of the reason for the collapse of the original East African Community again signed a treaty to re-establish it. At this point, it became apparently clear that there were external forces that planned and executed the fall of the old East African Community and so the leaders became even more committed to its reconstitution. The treaty came into force in July 2000 and the new East African Cooperation was established. One of the immediate tasks for the new Community was to identify areas of common economic interests that would serve as the nuclear centres for regional economic growth. For a number of good and legitimate reasons, Lake Victoria and its basin was identified and designated the pioneer economic growth zone that would foster regional socio-economic cohesion. Every state is expected to pay special attention to Lake Victoria basin with a view to promoting investment in the area in order to transform it into a real economic growth zone for East Africa. To achieve this, it is envisaged that a broad partnership of local communities, riparian states and the Community as well as development partners will have to be strengthened through programmes that focus on issues concerning Lake Victoria basin. It is expected that the programmes would include investment opportunities, one of which would be energy development. All these would place strong emphasis on poverty eradication, participation of the local communities, and sustainable development practices that are cognizant of environmental protection. Given the important role of energy in development, it has been earmarked as one of the top priorities for the Lake Victoria region. It must be pointed out here that all the traditional three East African states each has its own energy master plan that adequately covers their respective sections of the lake basin and provide massive investment opportunities in Renewable Energy Developments. The specific opportunity area includes, but not limited to, energy production and supply; improvement of infrastructure to enhance distribution of petroleum products; biomass development; production and sale of biomass processing kilns and stoves. In order to provide a well-coordinated management of investment issues, the Community has, in accordance with the Protocol for Sustainable Development, established Lake Victoria Basin Commission as an overall institution to handle development issues in the basin. The Commission, which is residing in Kisumu—a Kenyan city and port on the shores of Lake Victoria, recognizes the importance of participatory approach to development programmes and is ready to mobilize support for programmes initiated by the local communities and national governments. It appears this basin will in future play a very important role as the converging point or hub of the development of East Africa. Although it has a vast hydro energy potential and valuable fishery, it is also one of the areas with the highest poverty and lowest electrification levels in East Africa. It is therefore important to understand the conditions in the basin, its resources, energy potentials, and the role it can play in accelerating the development of the region.

Lake Victoria is a significant resource that has been shared by the peoples of East Africa since time immemorial. The economic activities around this lake are to a large extent a measure of what is taking place in the whole region. The area has a whole range of activities from agriculture to industries and has people of all classes from the richest to the very poor by any standards. Lake Victoria basin is also the home of three cities: Kampala the capital city of Uganda, Mwanza the second largest city in Tanzania and Kisumu the third largest city in Kenya (Fig. 2.1). For this reason it is necessary to give brief background information of the conditions in this region in order to understand energy distribution problems in East Africa. The region may have its own unique features but, in terms of resource management and energy supply, there are similarities with other regions in Sub-Saharan Africa.

Lake Victoria with a surface area of 68,800 km^2 and catchments area of about 181,000 km^2, is the world's second largest freshwater body (second only to Lake Superior of North America in size), and the largest in the developing world. It has a shoreline of approximately 3500 km long with 550 km in Kenya, 1150 km in Uganda and 1750 km in Tanzania. The lake lies across the Equator in its northern reaches, and is between latitude 0.7^o N–3^o S and longitude 31.8^o E–34.8^o E. It is a relatively shallow lake with an average depth of 40 m and a maximum depth of 80 m. The area usually referred to as the lake basin is larger than the catchments area and is estimated to be about 193,000 km^2 distributed in Tanzania (44 %), Kenya (22 %), Uganda (16 %), Rwanda (11 %) and Burundi (7 %) [3, 4]. This area supports a population of about 30 million people, that is, 30 % of the total population of East Africa lives in this area, which is only about 10 % of the total area of the region. The lake itself is however shared by only three riparian states of Kenya,

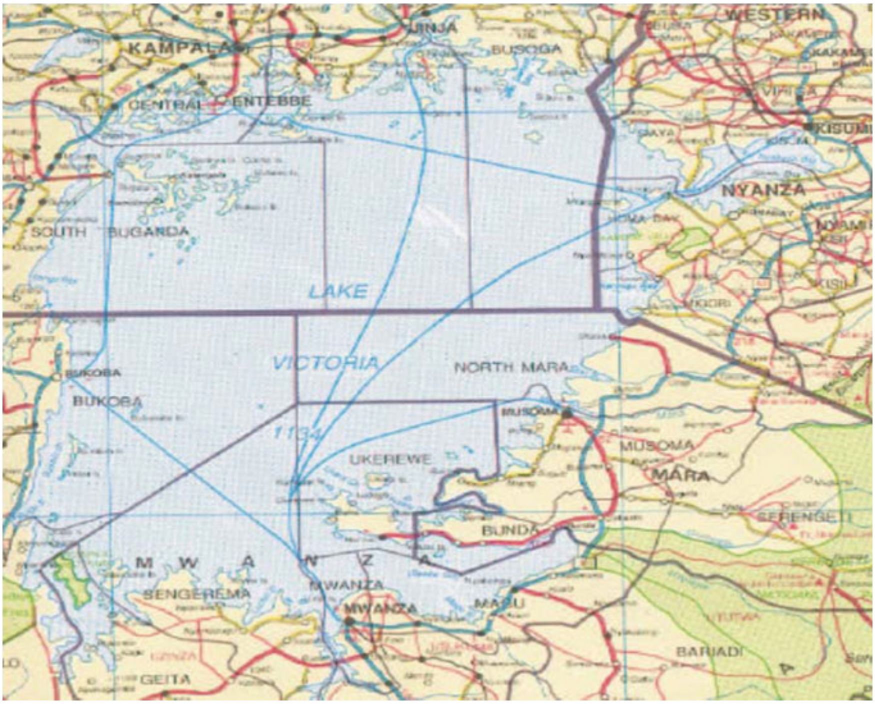


Fig. 2.1 Map of Lake Victoria [2, 3]

Uganda and Tanzania each controlling 4113 km^2, 31,001 km^2 and 33,756 km^2 respectively (Table 2.1).

Fishery is an important resource of the lake and is one of the most prolific and productive inland fisheries in Africa. At one time the lake was home to over 5000 endemic fish species but, as pollution load increased as a result of increased industrial activities and a growing number of human settlements around the lake, the number of fish species drastically declined. There is also local belief, without any credible proof, that the introduction of exotic species particularly Nile Perch

Table 2.1 Some statistics on Lake Victoria and its Basin [2, 3]

Country	Lake surface area		Catchment area		Lake shoreline	
	sq km	%	sq km	%	km	%
Kenya	4113	6	38,913	21.5	550	17
Uganda	31,001	45	28,857	15.9	1150	33
Tanzania	33,756	49	79,750	44	1750	50
Burundi	–	–	13,060	7.2	–	–
Rwanda	–	–	20,550	11.4	–	–
Total						

also caused the decline of fish species in the lake. Despite these changes, fisheries remain a very important source of foreign exchange earnings with an annual landed quantity of about 500,000 metric tons with an estimated value of USD 300–400 millions. However, there are indications that if the lake is not protected against continued pollution and over fishing, then the economic value of the lake will significantly diminish.

Over the years, dynamic fluctuations have been observed in fish production from Lake Victoria due to a number of factors but in recent years these changes began to take a generally consistent reduction trend. In Uganda, yields rose from 100,000 metric tons in 1980 to 132,400 metric tons in the 1989. From that period the catches have been gradually reducing so that in 1995 the catch was down to 106,000 metric tons and continues to fall. In Tanzania, annual catch increased from 146,000 metric tons in 1988 to 231,600 metric tons in 1990 and a general decline observed thereafter. In Kenya, the catch rose marginally from 186,000 metric tons in 1989 to 190,000 metric tons in 1993. Since then the catch has been going down. These trends can be explained by the fact that the apparent increases of the 1980s led to the establishment of more large scale fish processing plants along the shores of Lake Victoria, which target the international fish markets of Europe and Asia. This development raised the demand for fish and consequently led to over-fishing, which initially could not be controlled due to corruption involving powerful fish processors. The numbers of fish processing industries in the Region appears to have stabilized at about 34 factories almost equally distributed among the three riparian states: 12 in Kenya, 10 in Uganda and 12 in Tanzania. The irony is that although the lake's basin is rich in resources particularly fisheries, the community living in the region are one of the poorest in East Africa especially in Kenya and Tanzania. It is estimated that over 50 % of them live below poverty line. Despite the vast economic potential, investment in the Basin by both local and international entrepreneurs is still very low hence high level of poverty. The relationship between poverty and environmental degradation has been demonstrated by a number of scholars and the lake basin appears to be caught up in this situation in which one condition causes the other and vice versa—a vicious circle that has caused severe damage in the region. There have been major environmental shocks as a result of deforestation, destruction and drainage of wetlands, poor agricultural practices and direct discharge of untreated (or inadequately treated) industrial and municipal wastes into the lake [3]. Deforestation is due to a number of biomass uses but it is generally accepted that energy application is a major contributing factor [1].

Of the various uses/benefits from Lake Victoria [see, e.g., 3], it is fish that receives most attention. Most of the indigenous fish species in the lake lived between two million and ten thousand years ago in the west flowing rivers that later flooded to form the lake. The lake has since experienced explosive speciation particularly amongst the haplochromine cichlids, estimated to comprise over 300 species. This burst of speciation has been in response to the change from river to lake conditions. Although similar phenomena happened in other lakes, in Lake Victoria it happened much more recently, more rapidly and with fewer opportunities for ecological isolation in different types of habitats.

Within the period 1960–1990s, the native Tilapia (*Oreochromisesculentus*), previously a fish of the greatest commercial importance, virtually disappeared from the lake, but is still found in small quantities within the satellite lakes. Other fish species that have declined drastically include the migratory species, and the haplochromine cichlids. At the same time both Nile perch (*Latesniloticus*) and Nile tilapia (*Oreochromisniloticus*) have established themselves in the lake to the extent that they now dominate the commercial fisheries of Lake Victoria. The sardine-like native fish (*Rastrineobolaargentea*), locally known as "*dagaa/omena/mukene*", now features prominently among the commercial catches [2, 3].

The catchments area of Lake Victoria is slowly being degraded due to deforestation. The increase in human population in the riparian area has put pressure on the forests for agricultural land, timber, firewood (biomass energy) and habitation. This deforestation, coupled with bad agricultural practices, has degraded the soil leading to siltation along the rivers into the lake. Agro-chemicals and industrial effluents are now polluting the lake, while deforestation, soil erosion, and increasing human and livestock populations have all contributed to increased nutrient loading because of changing land use patterns. Sewage effluents from urban centres, beach settlements and fisher communities around the lake also contribute to the big nutrient load, which in turn has brought about eutrophication. This has increased algal populations, caused de-oxygenation of deep water and created conditions favourable for the growth of noxious weeds such as water hyacinth.

Wetlands, which normally filter the water before entering the lake, are under stress. Wetlands are reclaimed for agriculture, industrial development and human settlements, while others are drained to control human disease vectors. Some are excessively harvested for making mats, baskets and chairs. Many of the wetlands have received too much pollution to the extent that they cannot perform their filtration function efficiently. Therefore, pollutants normally retained by wetlands enter the lake unchecked, thus further contributing to the deterioration of the lake water. These wetlands also served as breeding ground for many fish species and their destruction must have contributed to the dwindling number of fish species.

Poverty in the region is rampant and, looking at the statistical figures on the Kenyan side, the trend has been upward. For instance, food poverty in Nyanza (Lake Victoria region of Kenya) was way above average at 58 % in 1997. Food poverty in Kisumu district rose from 44 % in 1994 to 53 % in 1997, while overall poverty in the city jumped from 48 % in 1994 to 64 % in 1997. To date, the situation has not improved [2, 3, 6].

The problems can be looked at in two categories i.e. at micro and macro levels. At micro level, the problems are people-based and therefore, through community structures, everyone should play a positive role in improving the conditions. While at macro level the problems cut across several sectors, and the governments of the three East African countries should play a leading role by providing an enabling environment.

Figure 2.2 shows the relative sizes of the East African states while Table 2.2 gives a summary of the important facts about the region. Rwanda and Burundi which are located along the North-Western border of Tanzania became members of

Fig. 2.2 Map of East Africa (Kenya, Uganda and Tanzania) [17]

the East African Community only recently and are not covered in the present analysis of the East African states.

2.2.1 Energy Mix Perspectives

Energy is required by all countries; some have it in abundance while others do not have enough to meet domestic demand and must get it from external sources. Thus energy is a sensitive global issue and so it is not possible to exclusively discuss

Table 2.2 Basic facts about East Africa (figures are averages from several sources)

	Kenya	Uganda	Tanzania
Land area (km^2)	569,250	199,710	886,037
Water area (km^2)	13,400	36,330	59,050
Arable land	8	n.a	4.5
Independence (year)	1963	1962	1961
Former administrator	United Kingdom	United Kingdom	United Kingdom on behalf of UN
Population (millions)	45.5	38.8	50.8 (all 2014 estimates)
Population below poverty line (%)	50	31	30 (2014 estimates)
Major natural resources	Soda ash, fluorspar, limestone, some gold, oil	Copper, cobalt, salt, limestone, oil	Tin, phosphates, iron ore, coal, diamond, gold, nickel, natural gas
Main agricultural products	Coffee, tea, sugar cane, pyrethrum, fisheries	Coffee, tea, cotton, tobacco, fisheries	Coffee, sisal, cotton, tea, pyrethrum, cloves, tobacco, cashew nuts, fisheries
Geography	Lake Victoria, Indian ocean coastline, Mt. Kenya, Great Rift Valley, some small lakes	Lake Victoria, river Nile, Great Rift Valley, some small lakes	Lake Victoria, Mt. Kilimanjaro, Lake Tanganyika, Lake Malawi, Great Rift Valley, few small lakes, Indian ocean coastline
Climate	Ranges from tropical to arid, two rainy and dry seasons per year	Ranges from tropical to semi-arid in North Eastern parts	Ranges from tropical to temperate in the highlands
Paved roads (km)	Over 9000	Over 2500	Over 3900 (all estimates)
Fuel pipeline (km)	483 (petroleum)	–	1710 km TAZAM pipe line (Tanzania-Zambia pipeline)
Natural hazards	Floods, drought	–	–
Environmental issues	Water pollution, deforestation, soil erosion, poaching	Deforestation, soil erosion, poaching, wetland destruction, overgrazing	Deforestation, soil degradation, destruction of coral reefs, poaching

energy situation in one country without making references to regional and global aspects that affect the local situation. Therefore, as we look at specific countries, we will occasionally bring in some external relevant issues. In addition, energy is a commodity, which must be processed into ready-to-use form. So let us first consider domestic ready-to-use energy requirement. The top priority is heat energy mainly for cooking. The second priority is lighting that, like cooking, can be provided from a number of sources: oil, electricity and biomass. It should be understood that, in this context, the three sources are not further converted into any other form of energy but only into heat and light. The costs of oil and electricity are however higher than the cost of biomass, which is normally freely collected in most parts of the rural areas. Thus a middle-income family living in an urban set-up would make a completely different energy choice during vacation in the rural home. The point is, the choice about which type of energy source to use is more than economic consideration. It is a very tricky and delicate mixture of economics, availability and application and this is not limited to domestic energy needs only but it is also relevant in industrial energy considerations. It is for this reason that a low income family living in the city would crave for electricity because of the desire to power household appliances, which are the mode of city life but would use a different energy source for cooking and heating. On the other hand, a high-income city family may use electricity for cooking, lighting and powering household appliances but would use wood for space heating.

Industrial power considerations also look at a number of issues including industrial raw materials needed in the production line. For example, a sugar industry accumulates a lot of bagasse while at the same time it requires a lot of heat in its production boilers. The boilers produce steam some of which finally end up in the environment. In such a situation, the choice of fuel for the boilers would naturally be the abundant sugar cane bagasse and since steam is already one of the bye-products, the factory can go further and use the steam to generate electricity for its own use. On the other hand, if the industry needs only electrical power to run its machines, then it is more sensible to get the supply from existing power grid. A brick factory may need electricity for its support systems but use wood in the brick-firing kilns. It is therefore reasonable to conclude that energy choice is made on the basis of a number of factors and not just cost.

In general and in global terms, the level of industrial and economic development of a country determines the predominant source of energy and the range of other options available. Much of the energy used in the world today are exhaustible and are gradually becoming scarce while energy consumption rate is steadily increasing. More than 50 % of the energy that has been consumed in the last 2000 years was consumed in the last 100 years. During this period, there has been a significant shift from one primary source to another particularly in countries that experienced and benefited from the industrial revolution. For example, in 1950, coal was the major global source of energy while oil was a distant second source as shown in Fig. 2.3.

About 20 years later (1968), the contribution from petroleum had substantially increased while that of coal fell by a large margin (Fig. 2.4). Both petrol and natural gas were rapidly replacing coal as the source of energy for space heating, electricity generation, transport and cooking. New technologies, particularly nuclear, were developed with more attention given to the fact that petroleum and natural gas were set to be the major sources of energy for transport vehicles and other mechanical

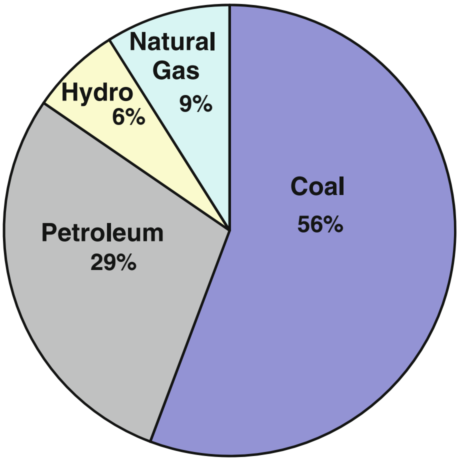


Fig. 2.3 Contributions of commercial energies in world energy supply, 1950 [29]

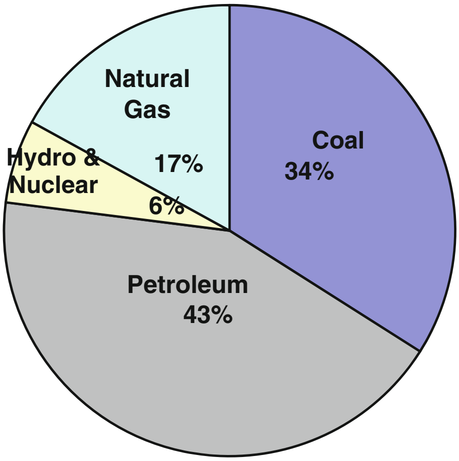


Fig. 2.4 Commercial energy resources and their world contributions in 1968 [29]

machines and, as a result, technologies such as steam engines that relied on coal began to decline. These changes took place more rapidly in the industrialized nations. For example, in the United States of America, use of petroleum increased from 14 % in 1920 to 50 % in 1980 while use of coal decreased from 78 to 18 % in the same period. The emergence of nuclear power also stifled further development of large hydro power plants. By 1980 both petroleum and natural gas contributed more than 75 % of the total energy consumption in the USA [29, 32]. These changes occurred principally due to increased technological and industrial developments that substantially improved the economies so that more and more people were able to afford and hence demand cleaner energies.

The two events (industrial development and increased consumption of clean commercial energies) are mutually dependent so that one leads to the other and vice versa. The large consumption of coal in those days is comparable to the present high consumption of wood fuel in the developing countries particularly in Sub-Sahara Africa (including South Africa) as shown in Fig. 2.5. If South Africa is excluded then the average contribution from biomass would be as high as 80 % in western, Central and Eastern Africa region. Solid fuels include mainly coal from South Africa and some small quantities from the neighbouring states of Zimbabwe, Botswana, and Mozambique. However, wide scale biomass use is not restricted to Africa. Its contribution is reasonably large even in global terms since more than 50 % of the total world population still rely heavily on it. The use of biomass is largely limited to heat requirements, as it is unsuitable and inefficient when used for other purposes such as lighting. This naturally restricts its consumption and therefore, in global terms, the poor majority who depend on it consumes less than 20 % of the total world energy consumption. To understand this, it is important to consider the total world energy consumption from all sources and compare this with typical energy consumption in a developing country. Energy consumption in an East African state of Tanzania is presented in this comparative analysis but first the general situation in Sub-Saharan Africa is exposed as shown in Fig. 2.5.

Sub-Saharan Africa is a region of diverse energy resources that include oil deposits in western and central parts mainly in Nigeria, Angola, and Southern Sudan; large deposits of coal in southern Africa and natural gas in some countries. There are also geothermal energy resources particularly in Ethiopia, Kenya, and lately in Uganda [4, 29]. In addition to these, some of the major African rivers like Nile, Niger, Volta, Congo, Zambezi, Limpopo and Orange with huge hydro potential are in the Sub-Saharan region. All these make very little contribution to the total energy consumed in the region compared to biomass energies as shown in Fig. 2.5. Much of the oil consumed is in fact imported from outside the region while hydropower development is still below 10 % of the available potential [5, 9, 35, 36]. Let us first

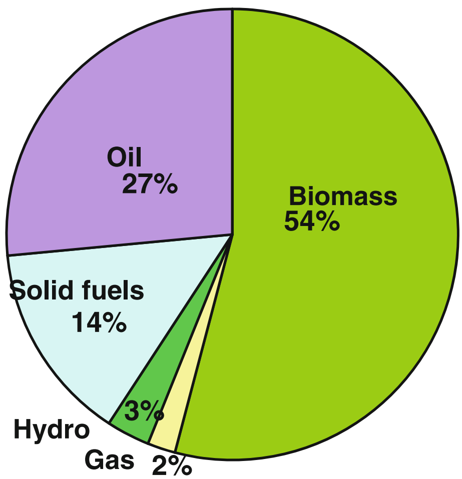
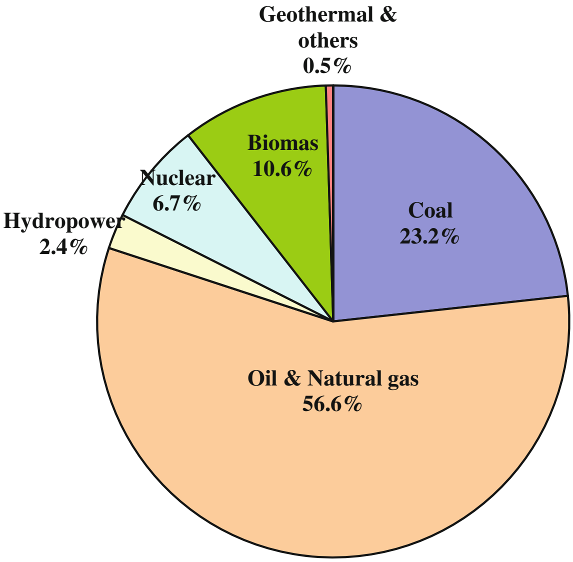


Fig. 2.5 Energy contribution by source in 1990 for Sub-Saharan Africa [29]

Fig. 2.6 World energy consumption by source in 2000 [29]



look at the total world energy consumption by source in order to understand the role of biomass energy.

The information given in Fig. 2.6 is based on the total world energy consumption, which was about 9.9 billion tons of oil equivalents in the year 2000. It is clear that biomass is still a significant source of energy even when all modern global energy sources are considered. Geothermal sources contributed about 0.46 % while the others included in that quarter (wind, solar, and tidal) contributed only 0.04 %. The situation in East Africa is remarkably different from that of the rest of the world and to illustrate this, we look at the Tanzanian case, which represents moderate situation in East Africa. In the same year (2000), Tanzania's total energy consumption was only about 15 million TOE distributed as shown in Fig. 2.7.

As has been severally mentioned, the rural population of the developing countries can be as high as 95 % of the total national population and almost all of them depend on biomass energy. Thus, apart from commercial energies used in transport and industrial sectors, biomass remains the main energy source. Its contribution, however, is generally higher than household consumption because it is also used in industries, agriculture and for other non-household applications. This is clearly shown in Fig. 2.8 where national biomass contribution for all sectors is 93.6 %.

The other sources of energy on which the government invests a substantial amount of money, contribute much less than expected and this is also indicative of the very low level of industrial establishments and poor transport system. Fossil fuels include oil products, coal and natural gas. In East Africa, Tanzania is the only country with some deposits of natural gas and coal. Both Uganda and Kenya have neither coal nor natural gas but since these have not made any impact in Tanzania, the energy consumption pattern is comparable to those in Uganda while Kenya,

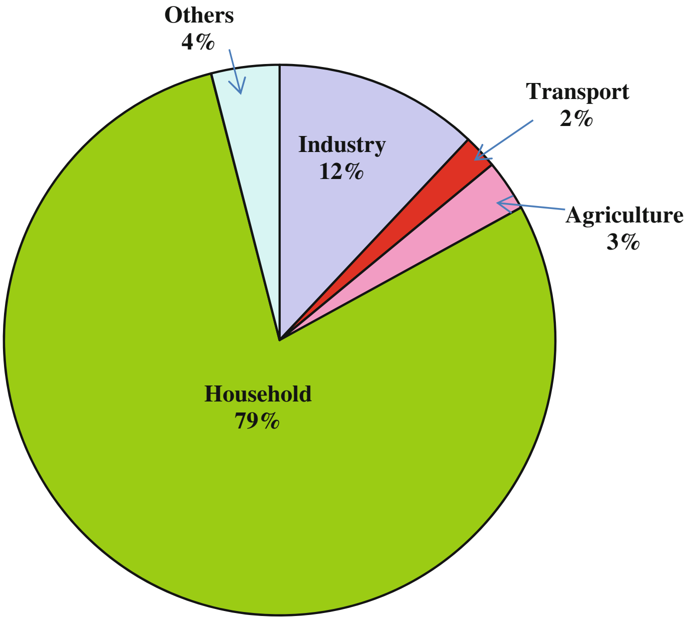
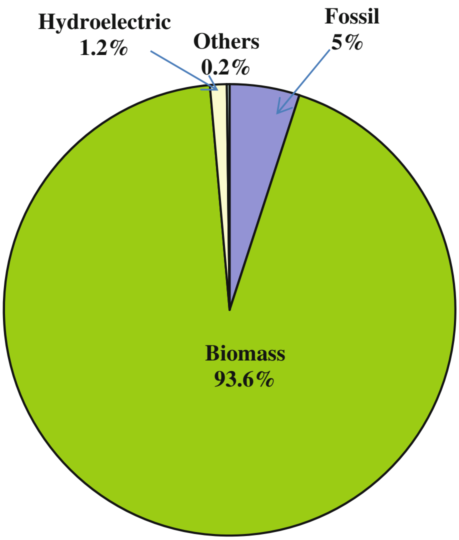


Fig. 2.7 Energy consumption by sector in Tanzania, 2000 [29]

Fig. 2.8 Energy contribution by source in Tanzania, 2000 [29]



with more developed industrial and agricultural sectors, spends relatively more energy in these sectors [31–33]. For example, Kenya's total energy consumption in the same year was also about 15 million TOE out of which biomass contributed about 79 %. Household energy consumption was however down to 68 % while transport, industry and agriculture consumed 12, 11 and 7 % respectively. Hydroelectric contribution was only about 1.8 % while imported fossil fuels accounted for about 19 %. So the pattern is basically similar with only small variations in sectoral consumptions.

The high dependence on biomass energy is a clear indication that the governments have not paid as much attention to energy development as they should. This may be one of the reasons for the very slow rate development process in the region. It should cause some concern not only for the governments but also for environmentalists since continued use of biomass has adverse consequences on soil fertility and environment in general [14, 15].

The big question for East Africa is whether the region whose average wood fuel consumption stands at about 85 % of the total energy can switch to cleaner energies, as did the USA and Western Europe. Oil was only recently discovered in Uganda and Kenya the impact will probably not be felt in the household energy scene for a long time to come. There is also the long history of corruption and poor resource management practices that need to be addressed if the region's oil is to improve energy access to the rural population. This was captured by president Obama (USA)'s address to Kenya during his visit in July 2015.

2.2.2 Household Energy Application and Management

Energy can be discussed from two viewpoints: its application and its source. For its use, there are priorities, which people tend to follow naturally particularly in household application where energy for cooking takes top priority followed by energy for lighting. Applications beyond these depend on family income. Whereas commercial energies are well managed, household energy demand and use is more complicated and are often affected by factors beyond government control. In East Africa, household energy accounts for over 80 % of the total energy requirement and so it is important to understand energy applications and sources for this sub-sector. East African countries are in a region of rich diversity in terms of geography, peoples, income levels and natural resources. Depending on family income level and traditional eating habits, household may prepare and eat up to four meals per day. This includes tea, porridge and other light meals. Some foods can take as long as four hours to cook while others may be prepared in a shorter time. About 95 % of the rural population rely entirely on wood for cooking using the traditional three-stone fireplace. A few households use the improved version of the three-stone in which the fire area is insulated with mud to reduce heat losses. A small number of households use more efficient baked clay stoves that were introduced and disseminated mainly by NGOs during the last twenty years. Wood is the main fuel for these stoves although the use of cow dung and crop residues is practiced in areas where wood is either scarce. Charcoal is the next important fuel for cooking mostly used by the urban poor but there has been a steady rise in the use of charcoal in the rural areas, especially areas where wood supply is well below demand. Charcoal is burned in simple metal stoves or improved ceramic-lined stoves with better fuel consumption efficiency. Local artisans make both stoves. Kerosene is widely available but is used only occasionally for quick cooking purposes because it is more expensive than biomass-based fuels and requires expensive wick stoves. Even those who can afford it hardly use it because of safety and the fact that food cooked on kerosene stove sometimes absorbs the fume that gives irritating smell to the food. The use of LPG is very limited particularly in Uganda due to the high costs and inadequate supply in the rural areas. Electricity similarly plays a very minor role as household energy for cooking principally due to its high cost and limited accessibility. Both Uganda and Kenya do not have coal reserves and therefore it is not used as household energy but some quantity is imported for industrial applications. There are some coal mines in southern Tanzania but it has not become a common household energy due to the general lack of marketing and infrastructure for it. Thus, biomass (wood, charcoal, crop residue and cow dung) is clearly the most important source of household energy for cooking in East Africa [13–15, 23].

Lighting is the second most important priority area for which energy is required. Although the available energy sources for this are expensive, most rural households can still afford to use some of them because of the short duration of lighting requirement. Each day, most families need light for an average of about three hours. Furthermore, cooking with firewood provide some light around the cooking area so that, sometimes, additional lighting may not be required if the whole family sits around the fire. On moonlight nights, cooking can be done outside the house and so reducing the need for lighting. Most households use kerosene as the source of lighting energy, using simple wick lamps with or without glass windshields. Kerosene consumption of these lamps is very low, making them very attractive to most rural households. Over 95 % of the rural population use these lamps even though kerosene itself is expensive for them. Use of the more expensive dry cells is also common but their application is limited to flashing only, when it is desirable to identify an object. Some lead acid batteries are used for lighting and entertainment but this is severely restricted by both the cost and lack of recharging facilities within easy reach. Similarly, solar photovoltaic systems have not made any significant impact as rural lighting energy for a number of reasons including high initial cost. All other household energy needs such as for radio, space and water heating are constrained by poverty and are therefore mostly unmet for the majority of the low income households.

Energy sources will be discussed later but a brief mention now will suffice to shed some light into the underlying problems in the supply of household energy. The region has a wide diversity of energy sources, which are used for similarly diverse applications. The use of the various sources is prominently constrained by poverty. On average, about 45 % of the population live on less than one US Dollar a day but about 90 % live on less than three US Dollars a day. This means that most people cannot fully meet their basic needs such as decent meals, clothing, healthcare, energy and sanitary residential conditions. They have to struggle to obtain most of these by employing own production strategies and heavy reliance on natural products especially for energy and healthcare (biomass and herbal medicine). This is why wood, supplemented by cow dung and crop residues, is overwhelmingly the single most important energy for cooking in the rural areas while charcoal is the dominant source for the urban poor. Most rural households (about 90 %) collect wood from the surrounding areas without having to pay for it while the others may mix buying and collecting. Urban households, on the other hand, buy all their charcoal and some small quantities of wood both of which are transported from the rural areas into the towns where there are several outlets, mainly within residential estates. The prices vary but usually remain affordable for the low-income groups. Crop residues and animal dung are exclusively for rural application where they are generated and used within the family's land and homestead. They are obtained freely and are not considered as commodities for sale. In some tribal customs, it is even a taboo to sell cow dung and agricultural waste and this means that anybody can collect them from anywhere [5, 14, 15, 19, 21, 22].

Table 2.3 shows the common sources of household energies and their relative contribution in TOE. Although these consumptions have some bearing on differences of national populations, it is evidently clear that Kenya consumes far less wood and charcoal than Uganda and Tanzania but its consumption of kerosene is much higher than in the two countries. One possible reason for this is the availability of oil refinery in Kenya and Kenya government's low tax on kerosene in addition to better distribution network in the rural areas. Kenya's per capita electricity consumption is also high, indicating that Kenya is already ahead of the other East African countries in the use of commercial energies [31–33].

Whereas commercial energy management is closely monitored at the national levels, there appears to be no overall or even coordinating policy at household energy level. Even the statistics on household energy consumption is not detailed and is usually collected by the national bureau of Statistics as an appendix to the national census records that are collected once in a decade. In addition, information on energy mix in terms of ratios, problems and constraints are usually not collected. Of course, the national policies of all the three East African states do consider household energy demand and supply but do so only as a responsibility and not as a commitment. The emphasis and action are on commercial energies and some concern is on sustainable use of biomass energies but virtually nothing is done to make clean household energy affordable. If energy is unaffordable, then it is not available. Uganda is the only country in East Africa that is concerned about affordability of energy for the rural households and has introduced measures to make energy available to rural households. Some of these include use of 'smart subsidies',

Table 2.3 Annual consumption of basic household energies in millions of toe

	Wood	Charcoal	Kerosene
Kenya	4.1	0.6	0.3
Tanzania	11	1.5	0.02
Uganda	5.3	2.3	0.04

prepayment meters, use of load limiters and leasing of PV systems. Tanzanian consumers are already using prepaid meters while all these are still alien to the Kenyan consumers. In general, the confusion with which rural household energy is managed arises from national resource management arrangements, which tend to scatter household energy issues in different government ministries. For example in Kenya, biomass issues are handled by the ministries of Environment, Agriculture and, to some extent, ministry of Energy, and each of these ministries may not be really concerned about energy par se but other functions of biomass as well.

2.2.3 Commercial Energy Management

Fossil-based fuels and electricity are the two main energy resources, which are of both commercial and political interest in East Africa. Oil includes diesel, petrol, kerosene, aviation fuel and LPG and is a versatile energy source that can be used to produce most of other forms of energy including the generation of electricity. Tanzania has some coal with significant commercial value but its contribution in national energy scene, at present, is very limited. It will not therefore be discussed in details. Up to the year 2005, there were no known exploitable oil reserves in the region but active exploration has been, and is still going on within the region with some discoveries having been made in Kenya and Uganda. These are going on under various agreements between multinational oil companies and the individual state governments. East Africa is the only region in Africa that has been a net crude oil importer and Kenya is the region's largest consumer and ranks overall 9th in Africa. The region therefore has been importing all its oil requirements mainly from United Arab Emirates in the Middle East. In 1988, an oil company found oil at a depth of about 4000 m in Isiolo district in Kenya but it was considered economically unviable to exploit.

Energy use for commercial and industrial purposes is well managed through an organized demand-supply system controlled by both governments and the private sector as the major stakeholders. Prior to the so-called energy sector liberalization of the late 1990s, oil was imported into the region in its crude form and then refined at the coastal city of Mombasa in Kenya and also in Tanzania. The importation of oil was closely controlled by national oil companies, which were allocated both import and distribution quarters. The Tanzanian refinery was later closed down and converted into storage facility on the basis of expert recommendation. Uganda is landlocked, has no oil refinery facility and has to depend on imports of refined products mainly through Kenya whose refinery is capable of processing about 90,000 barrels of oil compared to the Tanzanian refinery, which had a capacity for only 14,900 barrels per day. Both these refineries had not only been operating below capacity but had also been facing management and financial problems. Obsolescence is also an issue for the Kenyan refinery for which up-grading overhaul has been recommended.

The Kenyan oil refinery was farther affected by the liberalization of the energy sector that allowed oil companies to import refined oil directly from the oil producing countries. As the three East African states get closer together again through the re-established East African Community, several agreements have been put in place to improve the energy sector. For example, Uganda and Kenya have agreed to extend the Kenyan oil pipeline from the town of Eldoret in western Kenya to Kampala, Uganda (320 km) in order to efficiently serve Uganda and its neighbours such as Rwanda, Burundi, eastern parts of the Democratic Republic of Congo and northern part of Tanzania. Tanzania completed the Tanzania to Zambia (TAZAM) pipeline to Zambia covering a total of 1710 km. The pipeline that has a capacity of 1.1 million tons annually is owned jointly by governments of Tanzania (33 %) and Zambia (67 %) [8, 9, 29]. There is also a plan to construct another pipeline from Dar-es-Salaam to the Lake Victoria city of Mwanza in northern Tanzania (1104 km) to serve Uganda, Rwanda, Burundi and Democratic Republic of Congo. Since oil consumption is steadily increasing in the region, Kenyan refinery at its present capacity will not be able to adequately serve the region. Even if it is upgraded to a higher capacity, it will still not be sufficient for the future increased demand. East Africa by 2012 consumed about 100,000 barrels per day with Kenya as the major consumer of over 60 % of this. Although Uganda consumes less than one quarter of Kenya's consumption, it spends about 12 % of its total import bill on oil importation while Kenya's consumption is about 20 % of its import bill and so, in general, importation of oil by the three East African states is putting a lot of strain on their economies. Table 2.4 shows some oil related statistics in the three countries —consumption, percentage contribution to energy and percentage of import bill.

Since 1980, the prices of oil products and commercial energies in general have significantly gone up, forcing the prices of other commodities to also increase. This has created socio-economic problems in the region as more middle-income groups fall back below the poverty line. The price of kerosene, used mostly by the low-income groups, has increased by about 170 % while charcoal has gone up by 60 % since 1980, pushing low-income groups farther into the fathoms of poverty. The costs of LPG and electricity have also increased by 75 and 70 % respectively. These increases are calculated against the prices of the fuels in US dollars and the value of the dollar is assumed to have remained constant during the same period.

Fluctuations of oil prices are the most dynamic among all commercial energies as both international market forces and internal politics affect them. This is an area that must be considered carefully as it can be the source of a serious internal oil crisis. For example, in the late 1990s oil prices sharply went up and the

Table 2.4 Some oil-related statistics in East Africa [29]

	Oil consumption (million barrels per year)	Percentage of total energy	Percentage import bill
Kenya	20	26	20
Uganda	3	7	12
Tanzania	5.5	7	n.a

governments blamed this on the market collusion by the multinational oil companies to increase their profit margin. These companies, on the other hand, considered this as an attempt by the governments to divert public attention from their poor economic management to the energy sector. This particular conflict led to the establishments of regulatory boards by Kenyan and Tanzanian governments to oversee the oil industries. In order to assess the effectiveness of such regulatory bodies, we look at a case in 2005 when the Kenya government reorganized the method of paying taxes on oil imports while keeping the tax level unchanged. The new tax payment method required oil companies to pay the tax upfront. The oil companies did not support this method and immediately raised the pump prices so that motorists had to pay more even though the local currency had made significant gains against the US dollar, lowering the import bill for the oil companies. This was a clear demonstration of how the cartel of oil companies can use their strength to maximize their profits against the government's regulatory mechanisms. This happened because the limited storage capacity is not capable of holding enough oil for a long time and therefore the government cannot afford to push oil companies to disrupt import supplies. The governments can be blackmailed by the oil cartels and so the regulatory mechanisms in this sub-sector should be reviewed to introduce an arrangement that would make sure the government is not held at ransom during difficult times.

Another interesting observation, which brings to doubt the pricing factors such as transport costs, is the fact that the pump price near the refinery facility is sometimes higher than the pump prices 800 km away. So although the governments are very sensitive to any events that are likely to affect the supply of oil into the region or that could adversely affect oil prices, there is very little they can do to locally control the situation. It is for these reasons that internal fluctuations of oil prices often cause sharp conflicts between multinational oil companies, which import and distribute oil in the region and the governments. Thus the looming global oil crisis that is likely to continue should cause serious concerns in East Africa and some early measures may be useful. However, despite the occasional conflicts that revolve around protection of interests, the governments and the oil companies have worked very closely on acquisition and distribution of petroleum products. Kenya Petroleum Refineries Limited (KPRL) is 50 % owned by the government of Kenya with remaining stake held by oil companies (Shell and BP having 17.1 % each while Chevron holds 15.8 %).

In 2005, the government announced its intention to spend up to USD 200 million to upgrade the refinery, which has been using hydro-skimming technology that produces large quantities of low-value fuel oil and insufficient high-value products. The proposed rehabilitation will enable the plant to produce unleaded fuels. Obviously, some of this expenditure will be passed on to the consumers through appropriate pricing of petroleum fuels in the local market—a move that will further intensify economic hardships that are already caused by the high prices due to increased worldwide demand for oil. In order to understand the management of petroleum as an important energy resource in East Africa, we take an example of how it has evolved in Kenya.

The Kenyan domestic consumption of petroleum products is comparatively high in the region and all of it is imported [7–9]. The point of quantitative control of oil imports is at the Kenya Petroleum Refinery Limited (KPRL) at the seaport of Mombasa located in the south east of Kenya on the shore of Indian Ocean. The refinery was incorporated in 1960 under Shell and BP oil companies but effectively started operating in 1963. Later more oil companies joined by buying shares in the company and in 1971 the government of Kenya acquired 50 % equity. The refinery uses technology that produces large quantities of low-value fuel oil and relatively less high-value white products. From the refinery, the products were initially transported to Nairobi, about 500 km away, through 35.55 cm (14-in.) diameter pipe but this was later extended to Kisumu and Eldoret in western parts of Kenya using smaller pipes. The pipelines transport about 60 % of all the petroleum products while Kenya Railways and several road transporters share the rest. The distribution is done through countrywide network of licensed petroleum stations owned by registered oil companies. Some of the products are exported to the neighbouring countries. Before the so-called liberalization of the sub-sector, the schedule of prices of petroleum products was developed by the minister for Finance in consultations with the Ministry of Energy and circulated to the oil companies for implementation. A number of factors such as procurement cost, processing, taxes, transport and profit margins were considered in working out the prices. However the pricing system was considered to be opaque and did not appear to have been based on sound economic considerations and therefore was considered to be a government scheme to manipulate demand in order to cope with imbalances. This created considerable suspicion and animosity between the government and oil dealers. There was need to develop longer term pricing structure that would enable oil companies to get adequate returns for the investment and plan ahead for expansion. These were some of the issues that forced the oil companies to demand for liberalization of the industry so that the supply and demand forces are allowed to determine the market prices. When this was finally done in the mid 1990s, oil companies were required to ensure that there is enough oil stock in the country to last thirty days and LPG for at least ten days. They were also allowed to choose to either import processed oil or use the refinery in the country in addition to other conditions. All aspects of government monopoly were removed and this encouraged new investors into the oil industry. Although the old companies still control about 75 % of the domestic distribution and retail markets, there are at least ten new entrants who are active in importation and distribution of petroleum products. The liberalization, however, seems to have increased insecurity of supply and weakened government control of the industry. All these are likely to change as a result of significant oil reserves that have been discovered in Kenya and Uganda.

The management of the electricity sub-sector is somewhat different from that of oil. Before the three East African states got their independence, the region was administered by the British government and the main source of electricity for both Uganda and Kenya was the hydro power station at Jinja in Uganda. One of the agreements made at the time of independence was that Uganda would continue to supply at least some 5 % of electricity to Kenya even if Kenya finally developed self-sufficiency in electricity production. To date, Kenya still gets a small quantity of electricity from Jinja although there are indications that Uganda is likely to terminate this arrangement due to increased electricity demand at home. Apart from this, all the three states generate their own electricity principally from hydro stations owned and managed by the state. In addition to hydropower, Kenya gets some of its electricity from geothermal facility located in the Rift Valley province. Other sources of electricity include large portable generators some of which were installed by independent power producers that were given licenses as a result of the liberalization of the power sector. Arrangements have also been made with Emergency Power Producers (EPPs) who specialize in supplementing power during crisis as a result of unexpected long period of drought. They normally use fossil fuel powered generators. Many of the current independent power producers emerged during the severe drought of 1997 when Kenya hurriedly invited EPPs to supplement the dwindling local production. All EPPs left after about four years of operation in the country. It is important to mention here that liberalization of the power sector was not the initiative of the governments but was part of the Structural Adjustment programme proposed and supported by principal international development agencies notably World Bank and IMF.

Almost all power producers inject their contributions into the national grid for distribution by a partially state-owned power company. In Kenya it is the Kenya Power and Lighting Company (KPLC) that managed the sale and distribution of electricity while in Tanzania and Uganda, Tanzanian Electricity Supply Company (TANESCO) and Uganda Electricity Board (UEB) respectively handled both generation and distribution. These companies or parastatal organizations, as they are commonly known, have in the past faced severe management and financial problems due to government interference particularly with regard to sourcing of funds from the electricity company for non-energy related developments and haphazard political decisions that adversely affect the management of the power sector. Some of these included not just over-employment but also engagement of unqualified people in the sector. Such problems are often spurred by politically motivated favours to specific population groups. Monopoly status of the said power companies has also had negative impact on the development of the independent and alternative power production.

Proposal under the liberalization programme suggested that the power companies should be split so that generation and distribution are managed by different companies and, at the same time, allow independent producers to have certain rights under various agreements. Such proposals may bring some improvements in the electricity sub-sector but are unlikely to solve the management problems. Nevertheless, some steps have been taken to implement the proposal and, in this respect, Kenya Electricity Generation Company (KenGen) has been created out of KPLC to handle generation of electricity in Kenya. Uganda too has made some changes that created other companies to share the responsibilities of UEB with Uganda Electricity Transmission Company (UETC) dealing with transmission while Uganda Electricity Generation Concession (UEGC) handling generation. Similar trend is taking place in Tanzania where TANESCO is split into three different companies each to oversee generation, transmission and distributions respectively. However, unlike the oil sub-sector, the governments are still expected to have significant control of the electricity sub-sector. It should be remembered that the establishments of the existing power generating facilities were made possible through loans or arrangements for which the governments are still responsible. Therefore whatever adjustments or restructuring taking place, the governments must still have significant roles to play in running the services.

In addition to the boards that oversee the management of specific energy sub-sectors, all commercial energies fall under specified government ministry. Due to frequent changes in which the number of government ministries are either reduced or increased, commercial energies have moved from one ministry to another or merged with other ministries over the years. One clear thing, however, is that all the three states have recognized the importance of these two sources of energy and have made sure that they are handled, at the top, by a government minister. Although the companies that run the two energy sources have the authority to manage their affairs in their own best interest, the governments expect them to also provide the services and goods to the people efficiently and at 'reasonable' prices. It is this relationship that has made it difficult for some of the companies particularly the electricity companies to meet both their economic and management desires. Structural Adjustments and liberalization principles require governments to deal with provision of enabling environment and leave private sector to handle provision of services. Energy sector, however, is so sensitive and important that the governments are not willing to give away all their controls over the sector. This dilemma is partly the reason why this sector has not had the expected growth rate in the region. Potential investors have all along looked at government involvement with a lot of suspicion. Historically, the three companies that have been in charge of electricity generation and distribution in East Africa have their roots in the East African Power and Lighting Company (EAP&LC), which was the sole company in charge of generation and distribution of electricity in East Africa. This company existed before the then East African Community broke up in the late 1970s and it had a vertically integrated monopoly in the generation, transmission and distribution of electricity in the region. With the disintegration of the Community, each state constituted its own power company, which basically adopted the management structure and the monopoly policy of the defunct EAP&LC. Because of this historical background, the regulatory mechanisms in the electricity sub-sector in the three states have remained largely similar. In all cases regulatory authorities are established by Acts of Parliament and therefore provide strong government presence in the electricity production and management. The policy deliberately discouraged any independent operator from investing in energy production, as it would be impossible to sell it. In developed economies such as USA and Europe, the policies are quite different and anyone is allowed to generate own power and sell it to the existing grid as long as the method used is safe and environmentally friendly. This demonstrates the difference a good policy can make if effectively implemented.

2.2.4 Energy Choice Factors

As developing countries, Kenya, Uganda and Tanzania still have to do a lot in order to provide basic requirements to their people. The 2005 estimates put the region's population at about 90 million people, out of which 80 % live in the rural areas. There is however a number of small but heavily populated settlement areas commonly known as Market or trading centres which are expected to eventually develop into Townships. Most of them spring up along major road networks due to trade prospects with travellers. They are nevertheless considered as part of the rural set-ups since they do not have organized service provision systems such as water, sanitation and infrastructure. Furthermore the people's life style in these places is basically rural in nature.

Generally, national grid power lines tend to follow major road networks for ease of maintenance and security and therefore many so-called market centres have access to electricity but a good number of their residents are not supplied with electricity despite its accessibility. This immediately raises questions about the factors that consumers have to consider in making energy choices. The generally poor infrastructure implies poor distribution of electricity. The improvement of infrastructure has proved to be too expensive for the governments due to the fact that rural settlements are so sparsely scattered that any communication system would require very complicated and expensive network. Population density can be as low as 20 people per square kilometre and even much less in some places. This low population density, coupled with the difficult terrains makes it extremely expensive to extend the electricity network to most parts of the rural areas especially if generation of power is centralized as is the case in East Africa. The distribution of oil-based fuels (petrol, diesel, kerosene and LPG) is also severely constrained by poor infrastructure. However, its transportability in the refined form enables traders at various levels to get involved in its commercial distribution, increasing its cost at every stage but giving the people the much needed opportunity to obtain it a little at a time. It is therefore too expensive for the rural communities whose monthly incomes are not only low but also regular in many cases. The concern in energy supply therefore goes beyond the availability of a preferred source of energy and encompasses the preparedness and ability of the rural communities to benefit from such energies. This could be done by appropriately packaging energy to suit both energy requirements and economic circumstances of the rural communities. Availability of energy when people cannot afford it does not make any sense.

Traditionally, energy supply for domestic applications among rural communities is the responsibility of women who can only recruit children to help. This has been so because the main source of energy has always been biomass materials such as wood, cow dung and agricultural wastes, which are largely obtained free of any charge. These were considered to be readily available that only needed to be collected and taken home. However, it is the simple tasks of collecting firewood, fetching water, preparing food for the family, taking care of children, cleaning the house, cloths, etc., that have over-burdened the women to the extent that they could not fully participate in many socio-economic developments such as education. As a result of this heavy responsibility of managing practically all household chores, rural women have remained at the bottom of the social strata with virtually nothing for their welfare or under their ownership and time spent on collection of energy resources has been one of the key factors in all this.

Despite the economic development and gender equality policies, the energy situation among rural communities has not changed and has continued to be a burden on women and children. Biomass is still the major source of energy for both cooking and lighting for most people in East Africa. Rural electrification coverage in the region is on average less than 2 %. If both urban and rural populations are considered then a total of 10 % of Kenya's population have access to electricity while only 6 % have access in Uganda. The situation is not likely to change in the foreseeable future and, with the dwindling biomass resources, the region is likely to face a severe energy crisis.

Several decades ago, abundant natural forests freely provided the wood fuel for practically all domestic energy requirements. As population increased, the demand for more land for settlement and food production also increased and naturally forest cover diminished. Women began to travel longer distances to fetch wood fuel and this made it necessary to start growing trees specifically to provide domestic energy. Soon there was a general concern for wood fuel supply and its conservation. Consequently, there was an increase in extension services on agro-forestry with significant support from various development agencies. Such programmes considered all aspects of wood requirements including improvements of efficiencies of wood and charcoal stoves. As a result of these activities, new designs and presumably more efficient stoves were introduced into the market. Despite all these efforts, the role of wood as a major source of rural energy has not changed but the use of charcoal stoves among rural communities has increased largely due to the success of the so-called improved ceramic stoves, which were first developed in Kenya. In general, however, energy distribution patterns by source between 1998 and 2005 are basically similar in the three states of East Africa and are likely to remain so unless drastic and perhaps revolutionary measures are adopted in the energy sector. Biomass is expected to remain the major source of energy in East Africa (Table 2.5). The high per capita electricity consumption in Kenya is attributed to the relatively high level of industrial development and the extent of commercial energy distribution particularly kerosene. Other sources of energy such as wind and photovoltaic solar systems, which can provide electricity to the rural communities, have made relatively small contributions despite the abundance of both wind and sunshine.

Although biomass is often associated with rural household energy, a significant amount is also used in agro-based industries such as sugar, tea, tobacco and brick-making industries. Rural schools and hospitals also consume a lot of biomass energy for cooking and heating.

Table 2.5 East African energy contribution statistics in percentages between 1998 and 2005 [29]

Source/type	Kenya	Uganda	Tanzania
Electricity	3	1	1.5
Oil	26	7	7
Biomass	70	92	91
Others	<1	–	0.5 (coal)
National household electrification levels	13	6	8
Per capita Electricity consumption/kWh per annum	125	50	60

Kerosene is considered to be too expensive for the rural poor. However, it is used by many rural households almost exclusively for lighting, for less than three hours each day. Therefore monthly expenditure on kerosene is kept as low as possible. This situation masks an unmet need, which is demonstrated when higher quality lighting is required. For example, when rural homes acquire biogas or electricity, lighting hours increase and so do evening activities that can improve their welfare. The use of kerosene by poor rural households despite its cost, strengthens the case for appropriate packaging of energy that enables consumers to get it in small quantities at a time. Rural application of LPG is limited and is restricted to the few high-income families who can afford it and have the means to fetch it from sparsely distributed rural petrol stations.

East Africa is a region of diversity in terms of geography, cultures, ethnic groups and level of income. The lifestyle of the people and the preferential use of energy resources are largely determined by family income but this is not the only factor. In general the household energy demand is for two basic requirements: cooking and lighting. When these have been adequately met, then the family can, if affordable, demand more energy for household appliances such as radios, torches and small television. Table 2.6 shows percentage energy contributions from various sources and presents an example of their prevailing uses by rural and urban households. The example is taken from Kenya where, on average, biomass energy contribution is about 80 % with petroleum and electricity contributions at 18 and 1.4 % respectively. Considering all sources of energy, rural households consume 57 % while urban households and commercial sector respectively consume 16 and 27 % of the total national energy consumption. The situation in Uganda and Tanzania follow a similar pattern and therefore these figures are good indications of the situation in the region.

The choice of which source to go for would depend on affordability and availability. Energy for cooking is the first priority and therefore it must be available all the time. Light is needed but if there is no energy for its provision, a family may do without it for a few days. However firewood does provide some amount of space lighting around the fireplace so that additional light source may not be required. Often, one source would be for cooking and another for lighting. For example in urban areas, the combination may be LPG (cooking) and electricity

Table 2.6 Total energy share in percentages for all sectors, 2000 [29]

	Firewood 36.3 %	Charcoal 38.1 %	Industrial wood 0.3 %	Wood wastes 0.5 %	Farm residue 5.3 %	Electricity 1.4 %	Oil 18 %	Total 100 %
Rural household	89	46		62	100	5	3	57
Urban households	2	36		38		26	5	16
Others (transport, commerce, agriculture)	9	18	100			69	92	27
Total in %	100	100	100	100	100	100	100	100
Totals in ‘000’ Giga Joules	252,000	264,000	1750	3520	37,000	9800	125,000	693,070

(lighting) or electricity (cooking and lighting) for high-income group while the middle-income group may choose charcoal and kerosene (cooking) and electricity (lighting). The urban poor would go for charcoal (cooking) and kerosene (lighting). Some urban elite would use wood for space heating but this is not based on economic considerations. In the rural set-up, availability and security of supply is an important factor and therefore the majority would use a combination of wood and kerosene for cooking and lighting respectively. Kerosene is preferred for lighting and is used only for short periods of 2–3 h each night and so its consumption is low and hence low expenditure on it. Attempts have been made to introduce a variety of sizes of LPG storage and application devices in an effort to increase affordability but this has been constrained by the general high level of rural poverty and doubts on its immediate accessibility when it runs out. Energy is so crucial that people want to make choices that will ensure that it is always there when needed. Table 2.7 shows total energy consumption by all sectors in East Africa and also indicates preferred fuel mix for various applications.

'All other sectors' include users that cannot be categorized as household such as cottage industries (brick-making, jaggeries, fish smoking, small bakeries, milk processing, etc.), transport, agriculture, commerce and industry. Charcoal consumption outside households is generally found in cottage industries such as commercial food kiosks and rural restaurants while schools, hospitals, tobacco and tea processing establishments use firewood. Farm residues include sugarcane bagasse used by sugar milling industries for steam production mostly in co-generation systems. The percentages are calculated on the basis of energy consumed in joules from the chosen source. For example, rural household firewood consumption is estimated to be about 700 million Giga Joules while petroleum and electricity consumption by all other sectors are 190 million and 15 million Giga Joules respectively.

The three main sources and types of energy (electricity, oil, and biomass) that are commonly used in East Africa are acquired through certain technologies that determine the extent to which they can be used in different places in the region. The choice would be based partly on the economic activities and the required final form

Table 2.7 Preferred fuel mix in percentages for three main consumption categories in East Africa in 2000 [29]

Fuel use category	Fire-wood	Char-coal	Industrial wood	Wood waste	Farm residue	Petroleum	Electricity	Total
Rural household	56	32	–	0.5	10	1	0.5	100
Urban household	5	90	–	1	0.1	2	1.9	100
All other sectors	12	27	0.5	1.5	20	36	3	100

of energy. The two forms that are commonly in demand are heat and electricity. Therefore the popularity or wide use of a particular form is determined by its convertibility to other forms and the required applications. For example, electricity is used for powering industrial machines and household appliances and can also be readily converted into heat and light. Similarly, oil-based fuels can be readily converted into heat and light but are not suitable for powering household appliances. Solid biomass, on the other hand can be converted into heat and light, but its quality of light is very low and rapidly consumes biomass materials. Of course there are possibilities of obtaining some form of oil and gas from biomass but these technologies are presently not widely used. Given these qualities, electricity would be the best choice because of its versatility followed by oil and then biomass. If the price is the determinant factor and the final application is heat-based then biomass would be the obvious choice followed by oil and then electricity. This is based on the assumption that the pricing includes only financial outlay for the fuel and its utilization appliances, and no consideration is given to non-monetary costs to the environment and the user. Finally, if the choice were based on availability and life style then the rural community would choose biomass, oil and electricity in that order, while urban population would go for electricity, oil and biomass. We see that in all these considerations, oil is the second energy choice while electricity and biomass switch positions depending on the local circumstances. These are the simple characteristics that energy planners often ignore and yet, for the end user they determine the choice of the energy source.

Therefore, assuming that the economy of East Africa remains nearly stagnant as is often the case, the situations presented in Tables 2.5, 2.6 and 2.7 will prevail for many years to come. This is because people will always make choices that are appropriate to their economic, social and geographical circumstances. Another factor that is often ignored is the role of dry cells and rechargeable lead acid batteries as sources of electric energy for rural population. Individual ownership and hence effective application controls make these devices very attractive in the rural set-up. Thus, we see that with dry cells, rechargeable batteries, a little kerosene and biomass, a rural household is not only able to meet all its energy requirements at an affordable rate but is also able to control the sourcing and application of the energy. Actually dry cells, lead-acid batteries and kerosene, although used by many poor people, are more expensive than grid electricity for lighting. It is therefore important to note that poor people often unwittingly end up using energy that is too expensive, simply because it can be acquired in small amounts and their use can be controlled. Dry cells, for example, are used only as flash lights and so a set can last as long as one month or more. Since biomass is considered the only energy source that can be obtained free of any charge, it also serves an energy security. However, as discussed earlier, biomass resource is under threat, in spite of valiant efforts to address security of supply and improve efficiency of use. Hidden costs of biomass include the longer hours and increased drudgery for women in procuring biomass fuel and using it in rudimentary appliances; and adverse health impacts from smoky kitchens, which are the norm in the rural areas.

2.2.5 Policy Framework

We have seen that industries and households whether poor or rich require either heat or electrical energy or both for various applications. Electrical energy is more preferred because of its conversion versatility and the fact that it is a high quality power source for industrial machines. The other sources cannot serve the same purpose or, if they do, would be too expensive. Oil however will continue to play its crucial role in the transport sector. Investments on commercial energies have been based on national funds, extended loans and grants but such resources are continually becoming scarce due to a number of reasons and this trend has increasingly become an inhibiting factor for energy development in the region. Such constraints are often used to persuade national governments to accept externally initiated policy changes in order to continue receiving development loans or grants from international development partners. The objective of such new policies is to offload management responsibilities from the government to the private sector to allow the governments to concentrate on creation of conducive business environment and not direct service provision to the people. At the same time such policies make the government's energy management more vulnerable to private sector influence, some of which may not be in the best interest of the state. The implementation of the liberalization policies in the energy sector in East Africa is a result of such policy changes. This is unfortunately happening at a time when most rural communities are still relying on wood as a major source of energy. Over reliance on large centralized hydro generating facilities has not provided the solution to this problem and very little effort, if any, has been made to implement viable alternative energy technologies. Consequently, the cost of generation and distribution of electricity has not reduced at a sufficient rate to satisfy the economic conditions of the people. It is estimated that the average cost of grid extension in conditions of low population density and difficult terrains can be as high as US dollars 10,000 per kilometre. Under such circumstances, grid extension is not cost effective and alternative electricity supply systems need to be considered if viable grid extension policies cannot be found. There are variations in power extension policies in East Africa but, in general, the consumer is expected to meet the cost of grid extension. In addition to this there are other payments such as minimum charge that the consumer has to pay every month whether power is consumed or not. The rural poor cannot afford all these costs and therefore attempts to implement them will not promote rural electrification. The policy therefore sends a very wrong signal even to those who can afford these charges and unless it is reviewed in favour of the consumer, then even if the available hydro potential in the region were to be developed, still the majority of people living in East Africa would not be able to use electricity because it would be too expensive for them and so reliance on wood fuel would continue.

Thus, continuing with the present trend of using expensive centralized large hydro stations is not a viable alternative to biomass. In addition, large hydro stations create ecological conflicts and displacement of a large number of people in the area. They also have problems of silt, which fill the dams during the rainy season and prevent full capacity generation. Operation below capacity is also a known problem during prolonged periods of drought. Such problems will always exist in addition to distribution problems, which cause frequent power disruptions. In Kenya alone, about 10,000 cases of such disruptions are reported each month. Other methods and more user-friendly policies in electricity generation and distribution should be explored with more vigour and deliberate planning. Decentralized systems that give the user some responsibilities in maintenance and control of applications would be cheaper and more likely to appeal to the rural population.

Oil, the other major commercial energy source, is also faced with similar problems of affordability but since the consumer can get it in small and hence affordable quantities and control its consumption, more and more people will be able to use it. This is a good example of how poor people end up using more expensive commodity simply because it is possible to obtain small quantities. However, increased demand for oil worldwide and the fears that oil reserves are dwindling will probably force the price to escalate beyond the reach of poor rural communities. The apparent increase in demand for kerosene as the main source of light among rural population may also force the price to go up and reduce its wide scale application. One would therefore wonder whether it is a good policy to promote the use of kerosene in a large scale or not. Increased demand would most probably trigger price increases that could severely hit the rural poor. It is a well-known fact that about 50 % of East Africans are living below poverty line and they would not be able to afford the cost of either electricity or kerosene should the prices go up significantly. Thus the question of rural energy supply has to do with both availability and affordability and so we cannot ignore the effect of cost when assessing demand levels. The success of kerosene as an energy source for lighting rural homes will continue to rely on distribution packages that give access to small quantities as discussed above. Such methods will have to be introduced in electricity consumption if it is to be attractive to the low-income groups.

2.3 Energy Sources

East Africa is endowed with a variety of energy resources that have potentials, which have not been fully exploited. There are a number of rivers, small and large, whose hydro power generating potentials are yet to be fully utilized. Geothermal sites and deposits of oil, coal and natural gas have been identified and some exploitation is in progress. Availability of biomass materials, which are a major source of heat energy, is an equally important aspect that are being considered. The region has a rich biodiversity in both flora and fauna. The vegetation cover includes tropical forests, savannah type of vegetation and arid and semi-arid characteristics. There are also mountainous regions such as Mt. Kilimanjaro, Mt. Kenya, and Mt. Elgon regions that experience fairly cold climate and high rainfall. On average, East Africa receives annual rainfall of about 1500 mm, which is sufficient for constant regeneration of vegetation. In the following sections, various energy sources are analysed.

2.3.1 Solar and Wind Energies

We have seen that there are some wind generators that are working quite well in the region. This is a clear indication that wind power can be successfully harnessed in East Africa. The highlands, coastal regions, and Lake Victoria basin have average wind speeds that are suitable for both power generation and water pumping. The few wind generators and wind pumps that have been installed have operated satisfactorily, producing power at reasonable levels. In Kenya, two local wind machine manufacturers, one near Nairobi and the other in Coast region have installed most of the over 350 pumps in the country. There are also a significant number of locally produced wind pumps in Tanzania. Using wind power to generate electricity has not been as widely practiced in the region. However, the two wind generators (150 and 200 kW) at Ngong near Nairobi (Fig. 2.9) and the 200 kW machine in Marsabit in Kenya as well as the 400 kW machine at Chunya Catholic Mission in Tanzania have all confirmed the viability of wind farms in the region. A small NGO known as Tanzania Traditional Energy Development and Environment Organization (TaTEDO), in its effort to promote wind generators, has installed a small wind turbine of capacity 600 W at its centre with support from an external donor agency.

In a recent development, the Tanzanian government stepped up support for feasibility study in northern Tanzania to establish whether a total of 50 MW wind generators could be installed. The Danish organization that participated in the study confirmed that there is enough wind speeds in Mkumbara area to operate wind generators. Another study conducted at Setchet site by researchers at the University of Dar-es-Salaam also found the annual average wind speed to be 8.3 ms^{-1}, which is sufficient to generate electricity in the area. Attempts have also been made to assess the viability of wind generators at Mkumbula, Karatu where wind speeds were found to be, on average, 4.5 ms^{-1}. Reasonable effort has been made to use wind power for water pumping. For example in Musoma, Magu and Tarime areas, wind pumps are used for irrigation. There are also some wind water pumping machines in Singida, Dodoma and other regions of Tanzania. Wind energy options should therefore be more seriously considered since its use for electricity generation is likely to play an important role in rural electrification because it is relatively cheaper than oil-fired generation facilities, particularly in remote inaccessible rural areas.

In Tanzania, a lot more local efforts have been put on the development of wind machines for water pumping than in other regions in East Africa. For example in the 1980s the government supported the installation of wind pumps to supply water to several villages especially in Singida region. Several workshops were also established with support from the government to encourage the production of prototype wind pumps. Such workshops were at Ubungo, Faculty of Engineering at the University of Dar-es-Salaam and Arusha Appropriate Technology Project, (now part of Centre for Agricultural Mechanization and Rural Technology). Some very good progress was made and machines produced and tested but their high cost prohibited their widespread use in the country. In Uganda, the situation is a little different since the government has not provided significant support for the development of wind machines. Those that are operating were installed by Non-governmental organizations such as the Roman Catholic Mission and the Church of Uganda. One government institution, the Karamoja Development Authority, installed some wind pumps but this is an isolated case in Uganda.

Figure 2.10 shows mean wind speeds for some selected sites in Kenya. The mean wind speeds in the coastal region of East Africa are, in general, more than 4 ms^{-1} as indicated by the two sites at Malindi and Lamu, which are both in the coastal region and are over 100 km apart but their mean wind speeds are almost the same. A similar trend has been observed along the Tanzanian coast. There are also a number of inland sites scattered all over East Africa that have mean wind speeds above 4 ms^{-1}. Marsabit in Kenya, for example, has mean wind speed of about 11.5 ms^{-1}.

Generally, particularly in Kenya, the altitude rises rapidly from sea level on the east coast to over 1500 m above sea level in the central parts of the country. There are various highlands in the region where wind speeds are sufficiently high and therefore suitable for application of wind energy. It has been established that wind power generation potential of about 345 Wm^{-2} is available in Nairobi, Eastern, North Eastern and Coast provinces of Kenya. Lake Victoria region, the highlands, and northern part of Kenya also experience regular wind speeds that can operate wind machines. Although it is evident that there is significant wind energy potential in the region that should be harnessed, it should also be noted that wind is a highly variable source of energy because its speed changes remarkably with time and

Fig. 2.9 Wind generators (5.1 MW) at Ngong Hill, Nairobi, Kenya

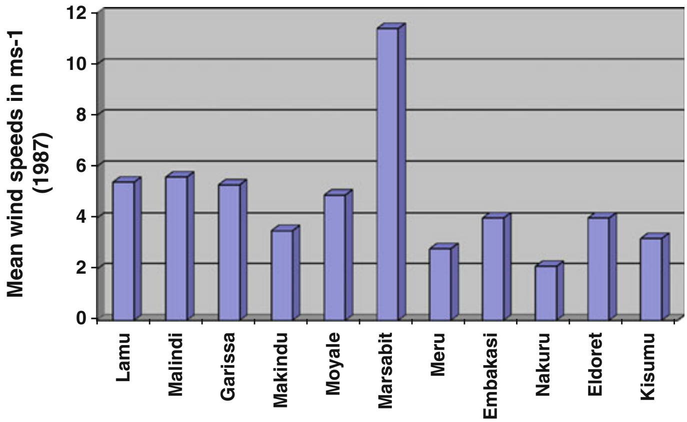


Fig. 2.10 Mean wind speeds (10 m above ground) in selected sites in Kenya [29]

location. However, through suitably designed mechanical linkages, wind power can be harnessed to drive water pumps or to generate electricity. Hence, the challenge in the development of wind energy technology is to design machines that can produce optimum energy safely and reliably. Even though the basic technology is simple, meeting this challenge requires highly sophisticated technology built on aerodynamic principles and using advanced materials and electronics. Thus, to develop a good machine for a given set of conditions requires a lot of financial and technical support. Unlike solar devices, wind machines must be matched with the local conditions where the machines are to be located. These constraints have retarded the widespread development and dissemination of wind energy technologies in East Africa as little research is carried out in the region to address technology challenges.

Both wind and solar energies are considered to be the most environmentally friendly sources of energy but their applications have been slow. The technology of solar energy conversion to electricity was virtually unknown in East Africa before the world oil crisis of the early 1970s, which triggered the need to search for other alternative energies. With a large percentage of urban population and almost all rural population having no access to national grid electricity, solar energy could play a significant role in domestic energy supply particularly for lighting. In the early phase of growth of the PV market in East Africa, the majority of the components for the systems were imported with the help of foreign donor funds. During the 1980s a domestic manufacturing expertise was gradually developed for solar thermal conversion while at the same time research on photovoltaic materials and production was encouraged in local universities. Although in East Africa not much was achieved in these areas, principally due to lack of institutional support, worldwide technological improvements however contributed to steady cost reduction of PV components. Potentially, a very large market for PV systems exists in Kenya, Uganda and Tanzania but to date implementation and their applications have been confined to affluent sections of society because of inadequate information and lack of distribution points in the rural areas. In 1996, it was reported that in Kenya about 40,000–60,000 households had installed solar energy systems, comprising more than 1 MW_p of PV power. In addition to such domestic installations, over the past ten years, several hundreds of PV refrigerators have been installed for safe storage of vaccines, several water-pumping projects have been initiated and programmes to make low-cost solar devices such as solar lanterns have been initiated in the region. The total population in the three East African countries has gone past the 90 million mark and is steadily increasing. The majority of these people need electricity mainly for lighting their homes and solar energy seems to have the solution for them. It is however important to develop local capacity for installation, maintenance, and after sales services in order to build user confidence in solar energy devices (PV systems, solar cookers, solar water heaters, solar dryers and solar lanterns, etc.). Sunlight is abundant in the region and with proper promotional activities, easy purchase terms, and good incentives from the governments; solar energy could hold the answer to rural electrification programme. Independent power producers could also be attracted to photovoltaic electricity generation. It is estimated that at the rate of 100 W photovoltaic panel for every 4 people, there would be 2400 MW of solar electricity to light every home in the region and this would cost about 7.2 billion dollars at the present price of $3 per watt. Kenya is already generating about half of this but serves less than 10 % of her total population. Obviously it has invested billions of dollars in the exiting generating facilities.

According to 2003 estimates, of the 140,000 m^2 of solar heat collectors for domestic water heating in Kenya, only 10 % is for household use, the rest are installed in hotels, hospitals and institutions such as schools and colleges. The potential for solar power is indeed enormous but unfortunately this source is not given prominence in all the energy development plans of the three East African States. The fact that solar energy devices give the user the opportunity to control their use and the satisfaction of ownership would make them attractive to the rural conditions if people are sensitised and given the correct information on their use and maintenance. With enhanced state support, it is expected that the rate of solar energy application will considerably increase. The average daily solar radiation in the region is about 21 MJm^{-2} day^{-1} with a minimum of 15M Jm^{-2} day^{-1} and a maximum of about 25 MJm^{-2} day^{-1}. The region straddles the equator and so there is abundant direct sunshine that generally rises to a peak of about 800 Wm^{-2} daily. Given these conditions and a large population of more than 100 million people without electricity, the potential for solar photovoltaic home systems is virtually untapped.

Solar energy can directly provide heat and electrical energies while kinetic energy of the wind can be converted to electrical energy through a generator and also to mechanical energy through appropriate mechanical linkages. All these final forms of energy are in high demand in any modern society. The conversion technologies for both solar and wind energies are well developed and their efficacies and suitability have been proven worldwide. However, they have not been adequately exploited in the region and the blame goes to national energy policies and implementation strategies that have not given these energy resources the attention they deserve. Although they are covered in energy policy documents their implementation is often limited to tax reductions given to those importing them into the region or end up simply as political rhetoric.

Over the years, a local capacity to fabricate solar water heaters has developed but there has been very little support for promotion. Such capacity exists in both Kenya and Tanzania where locally fabricated solar water heaters are used by both individual customers and institutions such as hospitals and hotels. Bugando Hospital in Mwanza, Makiungu Hospital in Singida, Morogoro Hotel, Hotel 77 in Arusha, kilimanjaro Christian Medical Centre, Manyoni Mission in Singida are a few examples of working solar thermal systems. In total, there are over 600 solar water heaters installed and working in Tanzania. There are also some photovoltaic solar systems for electricity generation installed and working in the region. Institutions such as hospitals, schools and hotels use the large ones while smaller ones are serving individual families in peri-urban and rural areas. It is estimated that over 50,000 photovoltaic panels of various power ratings are installed and operating in the rural areas of Kenya. Some large national corporations such as Posts and Telecommunication Corporations are using solar photovoltaic panels in their communication systems in order to enhance national coverage to include areas where there is no national grid electricity supply. National organizations in charge of wildlife protection are also using them to electrify fences in order to restrict the animals to the designated game parks.

Kenya has a well-developed market for the devices but, again, the official support is limited to tax concessions. Plans are underway to establish more wind machines to generate electricity in Kenya. It is encouraging that some level of wind energy technology exists in Kenya and there are a few local and reliable wind turbine manufacturers that can provide after sales services including spare parts. These manufacturers have locally produced and sold several wind machines mostly for water pumping in various parts of the country. During the 2013/2014 financial year, Kenya government declared its plan to increase wind energy development in its effort to boost overall national electricity generation. The costs involved are high and for this to fall, the challenge is twofold. At the development and production level, there is need to increase the energy conversion efficiencies and at the consumer level, the systems should be optimized. Unfortunately, research and production of solar cells require in-depth knowledge of structures of materials and fairly sophisticated technology. Therefore, researches that are done in the local universities are severely constrained by inability to acquire the needed high precision equipment. These issues must be addressed if energy generation through wind and solar are to be improved in the region. More information is available in specific publications for the three East African states of Kenya, Uganda and Tanzania [31–33].

2.3.2 Hydropower

Hydropower is the main source of electric energy in the region and although more than 90 % of the rural population has no access to electricity, the industrial production heavily depends on it for a wide range of applications. Electricity therefore can be considered to be the main driving force in industrialization process where it plays a pivotal role while oil sustains the transport sector. Both oil and electricity are sources of energy that are of extreme economic significance for any nation. More often than not, when talking about national energy plans and strategies in developing countries, the reference obviously is on oil and electricity. In fact, in the East African region, the word power means electricity while energy or fuel means oil. Although electricity accounts, on average, for less than 4 % of the total energy consumption in the region, while oil contributes less than 20 %, they are nevertheless the most important energy commodities for the national governments.

Oil has been imported into the region for many years and so did not require any special development plan but hydropower is internally generated and therefore needs careful production projections. Consequently, it is important to analyse the electricity sub-sector in details including the potential future role of hydro resources in rural energy supply strategies. In Kenya, electricity is produced from hydro, geothermal and fuel-operated generators. The present (2015) installed generation capacity is about 2290 MW but most facilities are operating below capacity due to a number of reasons. One of these is the occasional low level of water in the hydro dams as a result of prolonged periods of drought. Peak power demand however, is also low on average. But hydropower is not the only source of electricity. There are also other electricity sources from co-generator facilities and oil-powered generators. However, power generation is not steady because the capacity sometimes goes way below the demand due to a number of factors, forcing the distributor to ration electricity. A year of little rain than expected is a bad year for the power sector. The problem of increased silt in the dams is also experienced during too much rain reducing the amount of water and hence less electricity is generated. One very important aspect of the Kenyan hydro electricity generation is that more than half its installed capacity is generated from one river, the Tana river (Table 2.8). The major power stations on river Tana are Masinga, Kamburu, Gitaru, Kindaruma and Kiambere, and are known collectively as the Seven Forks Hydro Stations generating a total of 563 MW. The stations are not only along one river but they are also linked together by cascading water from one station to another taking advantage of the head pressure created by each dam. The dam at Masinga is used as the main reservoir that supplies the rest of the stations with water during the dry season. This linkage and their location on one river make all of them equally vulnerable to the effects of drought. The obvious result is that the country is likely to face occasional national electricity shortages when the river and its catchments experience dry spells even if there is enough rain in other parts of the country. Indeed, this has been practically experienced a number of times forcing the power company to enter into hasty negotiations with independent and emergency power producers who use oil-operated generators.

Table 2.8 Hydro power generation in Kenya [29]

Large hydro stations				
Station	Location (district/river)	Capacity (MW)	Year commissioned	Reservoir capacity (million m^3)
Masinga	Tana	40	1981	1560
Kamburu	Tana	94.2	1974	Underground station served by Masinga dam
Gitaru	Tana	225	1999	Water from Kamburu through 2.9 km tunnel
Kindaruma	Tana	44	1968	Water from Gitaru through 5 km tunnel
Kiambere	Tana	144	1988	585 (receives water from Kindaruma
Sonu-Miriu	Kisumu	60	2012	
Sangoro	Kisumu	20	2014	
Turkwel Gorge	West Pokot	106	1991	1600
Total installed capacity from large hydro stations		733.2		

In order to reduce the risk of power shortages, plans are underway to increase installed capacity by developing new plants as well as rehabilitating some of the old facilities. It is expected that Independent Power Producers will also have some contributions in these plans by injecting more power under 20 years power purchase agreement. A possibility of importing power from Tanzania through Arusha using 330 kV transmission line to Nairobi is also under consideration mainly because Uganda had to stop power export to Kenya due to increased demand at home. However, it is most unlikely that these developments will reduce power costs or increase electricity access to the ordinary rural Kenyans. Perhaps the only most important aspect of these arrangements is that they will diversify power sources from the Seven Forks system and increase security. There is also plan to import electricity from Ethiopia which is already developing a massive hydro power project on the Blue Nile.

The linkages in the Seven Forks system are very interesting and might have been favoured because of low construction cost. In addition to cascading water from one station to another, generated electricity is also in certain cases conveyed to another station before transmission to the national distribution point such as Nairobi, the capital city. For example, electricity generated at Masinga is first transmitted to Kamburu before transmission to Nairobi. Similarly, electricity from Gitaru is first transmitted to Kamburu. This means that electricity from the Seven Fork system can only be transmitted to Nairobi from three points: Kamburu, Kindaruma and Kiambere.

In addition to the large Seven Forks hydro stations and Turkwel Gorge, there are a number of small hydro stations some of which are now more than 50 years old and are still operating. The European settlers introduced many of the small hydropower machines in Kenya in the early and mid 20th century. A good number of them are no longer operating partly due to government's lack of interest in small hydro and partly because of aging and rising cost of maintenance. Table 2.9 gives the details of some small stations that are still in action. Small hydro systems with power ranging from 400 to 800 KW have been operating in the tea-growing areas of Kericho highlands where some European settlers are still doing some farming. Tenwek Hospital in the same area is one such example where a small 400 KW hydropower facility is used to provide power for lighting. In general small hydro systems have been used in Kenya since 1919 and compared to other technologies under similar conditions of lack of spares and maintenance knowledge, the small hydro power units have done reasonably well. At least, some of them are still operational. A survey carried out on small hydro potential in Kenya revealed that there are over 100 sites that are suitable for generation of more than 10 kW.

The Tanzanian hydro electricity production is smaller than the Kenyan system but targets a larger area. All hydropower generation is still done by the state monopoly company, the Tanzanian Electric Supply Company Limited (TANESCO) but plans are at an advanced stage to change this. The total installed hydro capacity is 561 MW generated as shown in Table 2.10 Kidatu is the largest hydro station in Tanzania with an installed capacity of 204 MW followed by Kihansi with an installed capacity of 180 MW. The rest are producing less than 100 MW with Nyumba ya Mungu being the smallest at only 8 MW. A small amount of hydropower is imported from the neighbouring countries such as Zambia (3 MW) and Uganda (10 MW). These are mainly used to serve the regions near the borders with these countries.

The Ugandan Electricity generation sub sector is the smallest in East Africa partly due to the fact that Uganda is the smallest in size and population in the region and partly due to stalled development programmes during the years of civil war of the early 1980s. The presence of river Nile with a large hydro potential has affected the development of small hydro power facilities but there are a few that were introduced by the colonial settlers and, more recently, by non-governmental organizations especially the church. Since the late 1986 when the country returned

Table 2.9 Small Hydro power stations in Kenya [29]

Station	Location (river/district)	Capacity (MW)	Year commissioned
Mesco	Maragua	0.38	1919
Ndula	Thika	2	1924
Tana	Upper Tana	14.4	1940 (3 machines) (additional 2 machines in 1953)
Sagana	UpperTana	1.5	1952
Gogo	Migori	2	1952
Sossiani	Sosiana	0.4	1955
Wanjii	Maragua	7.4	1955
Total capacity from small hydro		28.08	

Table 2.10 Hydro electricity production in Tanzania [29]

Station	Installed capacity (MW)
Kidatu	204
Kihansi	180
Mtera	80
Pangani	68
Hale	21
Nyumbaya Mungu	8
Total from Hydro	561

to peaceful governance, a number of sites for small hydro development have been identified and plans are underway to develop them using local expertise and locally fabricated equipment.

In the mid-1990s a survey was conducted in West Nile region and a total of about 80 sites with potential ranging from 2 KW to about 600 KW were identified. As for the large hydropower, the Nalubaale power station, which is located in the south-eastern part of Uganda at Owen Falls, on river Nile, is one of the oldest large electricity generating facilities in the region (Fig. 2.11). It has had, for a long time, a generating capacity of about 180 MW but the recent extension that brought in the Kiira Plant (Fig. 2.12) and Bujagali has increased the capacity to about 500 MW. The three stations on river Nile are the only major sources of hydropower in Uganda. Again the management of the electricity sub-sector has been done by the Uganda Electricity Board in a similar monopolistic approach as were in Kenya and Tanzania but the recently introduced reforms are set to change this in the whole region. However, it should be noted that, given the large variation in weather

Fig. 2.11 Nalubaale power station (formerly Owen Falls Dam) on rive Nile in Uganda

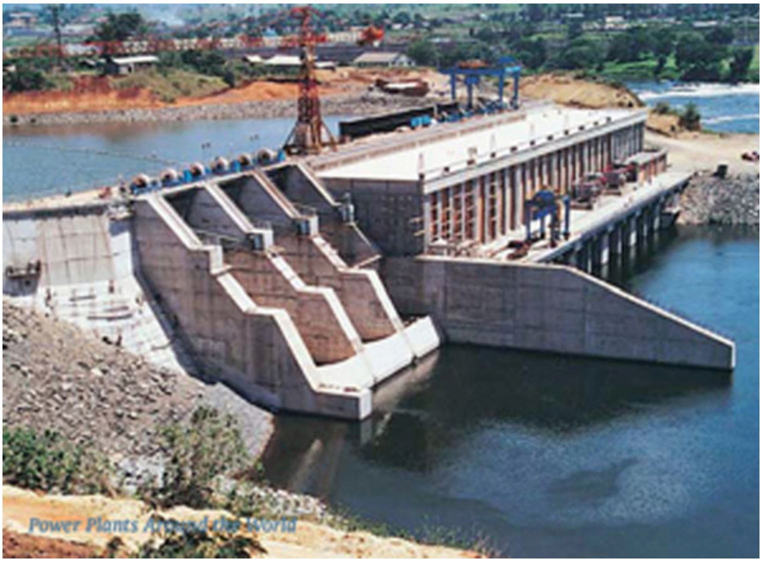


Fig. 2.12 Hydro power station at Kiira on River Nile in Uganda

conditions and the unpredictable nature of rainfall, over reliance on hydro power is like sitting on a time bomb. Some of the experiences in Kenya have underscored the need to speed up diversification of power sources. In many cases in Sub-Saharan Africa, data on electricity supply are not reliable [13].

For a long time Kenya got its electricity from Owen Fall Dam (now known as Nalubaale hydropower station) in Uganda under some special arrangements. However, Kenya later developed its own hydro stations mainly along River Tana. Together with hydro power stations in Tanzania, these facilities are now the major sources of electricity in East Africa. Table 2.11 gives, as an example, sources of electricity produced in Kenya. The situation in Uganda and Tanzania may be slightly different because Kenya is the only country in the region that is exploiting geothermal energy resource.

Lake Victoria, which is the source of river Nile is located almost at the centre of East Africa and is sometimes referred to as the Heart of Africa. The Equator crosses the northern part of the lake which is within Ugandan territory. River Nile is the only major river flowing out of the lake while several rivers flow into the lake mainly from the Kenyan and Tanzanian sides. River Nile traverses Uganda before proceeding on to Egypt through the vast Sudanese territory where it is joined by the Blue Nile from the Ethiopian highlands. It is one of the two longest rivers in the world with an estimated length of about 5580 km from Lake Victoria (Uganda) to the Mediterranean Sea (Egypt). With a high volume flow rate of about 600 m^3s^{-1}, river Nile gives Uganda a huge hydro power potential of about 2000 MW most of which has not been exploited. For many years, Uganda and, to lesser extent, Kenya depended on electricity generated at Owen Falls (now Nalubaale Dam) on River

Table 2.11 Sources of electricity in Kenya in 2014 [12]

Source	Capacity (MW)
Hydro	827.02
Fossil fuels (incl. gas, diesel and emergency power)	811.3
Geothermal	593
Bagasse cogeneration	38
Wind	25.5
Total	2294.82

Nile (Fig. 2.11). Uganda is further favoured by the fact that river Nile flows through the central part of the country making it possible to develop economically viable centralized generating facilities capable of electrifying the whole country. Despite the favourable distribution of her hydro potential, Uganda has only exploited less than 20 % of this and is the least electrified state in East Africa. However, for a small country like Uganda, the construction of large hydropower dams would have a great impact on the environment and displacement of people and so the development of hydropower should be carefully planned. Uganda has however planned to develop more hydro power stations along river Nile. Some of the identified potential hydro power stations are shown in Table 2.12.

Some of the sites listed on Table 2.12 are already undergoing development against stiff opposition from Ugandan environmentalists, particularly the Bujagali site, which was considered to be of cultural and ecological importance. A hydropower station was however later built on the site (Fig. 2.13).

There is also potential existing in other river regimes for small and medium power generation as shown in Table 2.13.

In total, over 20 small and medium hydropower sites have been identified in Uganda and since they are scattered in remote areas far from the main centralized large hydro site near the Lake Victoria port town of Jinja, they provide the country with a good opportunity for local independent power companies to produce electricity for isolated rural settlements and institutions such as schools and hospitals. The Uganda government has already put together a number of mini hydro projects that are expected to inject about 30 MW into the grid. They include West Nile

Table 2.12 Hydro power potential in Uganda [29]

Hydro power station	Estimated potential output (MW)
Ayago	580
Murchison Fall (Kabalega)	480
Kalagala	450
Bujagali	320 (partly developed)
Karuma (kamdini)	200
Estimated Total output	2030

Fig. 2.13 Bujagali hydropower station on River Nile in Uganda

Table 2.13 Small hydro potential in Uganda [29]

River	Estimated potential (MW)
Anyau	0.3
Bunyonyi	1.3
Nyakabuguka	0.2
Mpanga	0.4
Nyakabale	0.1
Ataki	0.2
Kisiizi	0.2
Kagera	2
Nyagak	3
Kaku	2.2
Maziba	0.5
Ruimi	1.5
Ishasha	6
Sagahi	6
Mubuku	7.5
Muzizi	11
Mtungu	12
Total estimated for small and medium hydro generation	54.4

Hydro Project (5.5 MW), Rukungiri-Bushenyi Power Project (4.6 MW), Kaseses Rural Electrification Project (5 MW) and the Buseruka Hydro Power Project (15.6 MW). Since Uganda covers small territory compared to Kenya and Tanzania, a single national grid network may serve her more effectively.

Like Uganda, Kenya's hydropower generation is dependent on one river Tana. The same river still has some undeveloped potential for more electricity generation at Mutonga, Grand Falls, Adamson's Falls and Kora Falls all of which have been identified for future development. The river, however, flows through a section of the country, which has relatively low population density, and power has to be transported long distances to reach the major towns and cities such Kisumu, Mombasa and the capital city Nairobi. Apart from river Tana, there are a number of smaller but permanent rivers flowing from the western ridge of the Great Rift Valley into Lake Victoria. These rivers have a great potential for small and medium hydropower facilities. A few, such as Magwagwa and Sondu/Miriu on river Miriu, Leshota, Oldoriko and Oleturat on river Ewaso Nyiro have been identified and targeted for development by KenGen but there are still about 100 sites with smaller hydro potentials on rivers like Yala, Athi, Mara and Turkwel systems. Within the tea estates of Kericho highlands, there are small rivers with potential for small hydropower production and indeed the viability of the systems have been proven by some institutions in the area that produce power from these rivers for their own consumption. In Tanzania, about 15 % of the estimated hydro potential of 4700 MW has been exploited. Rivers Rufiji, Mara and Kagera and their tributaries present Tanzania with a range of hydro potentials suitable for both small and large systems. On river Rufiji alone, hydro potential of over 2000 MW of installed capacity has been identified. The capacity exists for expansions of hydro projects at Rumakali and other existing hydro stations.

From Tables 2.12 and 2.14, it is clear that, compared to Uganda and Tanzania, Kenya does not have a high potential for large hydro schemes but has significant potential for small and micro hydro schemes. Kenya would therefore be better placed to develop small and micro hydropower facilities on its numerous small but permanent rivers scattered all over the country particularly in the western part of the

Table 2.14 Hydropower potentials in Kenya and Tanzania [29]

Kenya	MW	Tanzania	MW
SonduMiriu	60	Upper Kihansi (completed)	120
EwasoNyiro	90	Rumakali	222
Ewaso Basin	90	Ruhidji	358
		Masigira	118
		Stiegler's Gorge I	300
		Stiegler's Gorge II	750
		Stiegler's Gorge III	350
		Mandera	21
		Mpanga	160
Total	240	Total	2399

country, which at present does not have hydropower plant. The 60 MW Sondu Miriu hydro station was recently completed and is currently the only large generation facility in western Kenya. Other hydropower potentials on river Tana are not included in Table 2.14 but are possible extensions of the existing Seven Forks system, a move that may not be advisable given the vulnerability of the facilities to drought and the dire consequences as has been experienced in the past.

In general, East Africa has a vast hydro potential in excess of 6000 MW that can supply all electricity requirements in the region at the present consumption level. However, achieving this through single national grid power network using large hydro stations would not only be too expensive for the economies of the regional states but would also cause far reaching impact on the environment. Maintaining the current networks with very small national coverage is already proving to be difficult. Small hydro potential existing in the region, if developed as isolated units or grid connected when economically beneficial, offers good chances for rural electrification. It is worth noting that of the total World's hydropower potential, 27 % is in Africa (about 780,000 MW) while South America has about 20 % (577,000 MW). The remaining 53 % is shared among the rest of the world (Western Europe, United States of America, Canada, Eastern Europe, Asia, etc.). However, Africa has harnessed only less than 5 % of its hydro potential while South America, with comparatively less potential, is using more hydropower than Africa. The African continent needs to learn from the experiences of countries like China, which has a vast territory, served by several small and medium hydro systems, some of which are operating in isolation. So far more than 40 % of the Chinese hydro potential has been developed and there are about 50,000 installed small hydro units producing a total of about 6000 MW mainly for rural electrification.

The unique Chinese approach to rural electrification is the use of Micro hydro schemes with capacities of up to 100 kW (0.1 MW). In fact, there are several factories producing even smaller systems of up to 5 kW, referred to as Pico hydro schemes, which are exported to other countries especially to the Far East for rural electrification. Such machines are simple to install and require less than 5 m pressure head for their operation and weigh less than 50 kg. The cost comes to about USD 300 per kilowatt when installed.

Vietnam has been one of the major consumers of the Chinese so-called family hydro systems of 50–1000 W capacity. Today similar systems are manufactured in Hanoi and are readily available in the markets. These simple small machines require only up to 2.5 m of head and flow rate of just about 0.02 m^3s^{-1}. The 1000 W system, for example, requires 2–4 m head and flow rate of about 0.08 m^3s^{-1}. The technologies for these Micro and Pico hydro schemes are well developed and, if adopted by the developing nations in Africa, can make significant contribution in rural electrification. East Africa is capable of developing its vast small hydro potential to power practically all rural trading centres, schools, provincial and regional administration facilities, all fish landing beaches around Lake Victoria and any other centre of interest. Most of the already developed hydro schemes in East Africa are in 100 MW range. In general, hydro facilities are state controlled and supply about 60 % of the total electricity consumed in the region.

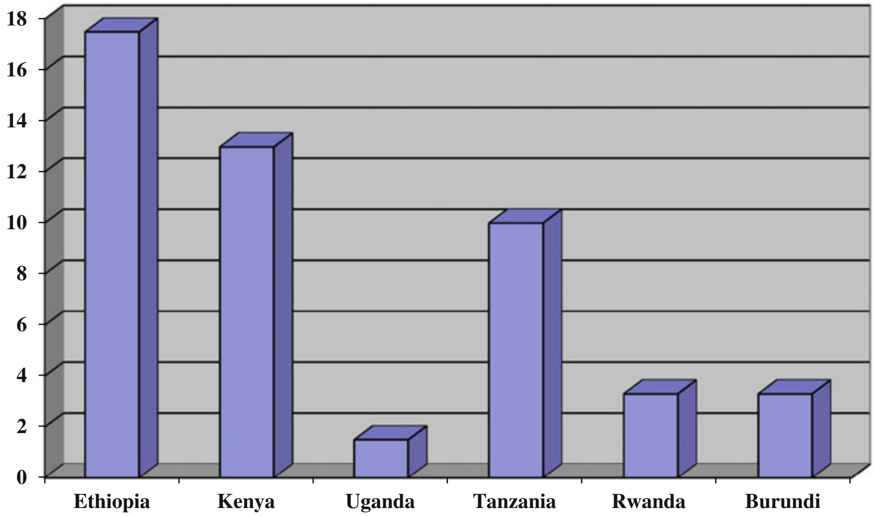


Fig. 2.14 Installed mini hydro schemes in Eastern Africa [29]

It has been shown that hydro power development can make a big difference in East Africa. But there is also need to change current energy policies that limits power distribution. The high connection fee paid by consumers without acquiring the right to own any of the components is just one way of suppressing the demand. State owned utilities are not likely to voluntarily change these policies but mini hydro schemes with user friendly payment packages and operated by communities and independent electricity providers can definitely make a difference for the rural communities in this region. Figure 2.14 shows installed mini hydro facilities in East Africa and some neighbouring countries. These are far below the available capacities.

2.3.3 Geothermal

Although some studies have indicated the possibility of finding geothermal sites in Tanzania, there has not been any concrete exploration plans. Similar studies have been done in Uganda with strong indications of geothermal potential estimated at about 450 MW from different sites but these have not been exploited. Kenya is the only country in the region that is already harnessing geothermal energy and is using it to generate over 500 MW of electricity from sites located in the Olkaria area of the Great Rift Valley. Kenya Electricity Generation Company (KenGen) in collaboration with other independent power producers continue to search for more geothermal sites. A number of sites have been identified and earmarked for development. Studies have been conducted around the present Olkaria area and also in Eburru field where expansion of existing facilities have been done. Studies have also been carried out around Lake Baringo as a result of natural occurrence of hot springs in the area but there have not been any conclusive findings. According to the present indications, geothermal potential in Kenya is in excess of 7000 MW. It is expected that the increased generation of electricity from geothermal sources will reduce the unit cost of electricity in Kenya because geothermal generation is considered to be the least cost energy in the region. Should more coal and natural gas be discovered, it is most likely that they will be used to generate electricity and not as domestic energy sources.

Geothermal energy is obtained from natural heat stored in rocks and water within the earth's crust. Since the energy is extracted by drilling wells to the underground hot aquifer, the wells should be shallow enough for energy production to be economically justifiable. The steam is led through pipes and finally used to turn turbines, which drive electricity generators. In Kenya, most of the stations are located at Olkaria near the southern shores of Lake Naivasha. The first of the three steam turbines producing a total of 45 MW started operating in 1981. About 33 wells have been dug to supply steam to the plant. The second phase of geothermal energy development known as Olkaria II has also been developed and is operational. The third geothermal site, Olkaria III, developed and totally owned by an independent electricity generating company is also operational. By the beginning of 2003, the new plant was already producing 13.5 MW and by 2005 it was completed bringing to 109 MW the total installed capacity at Olkaria. By 2015, total geothermal installed capacity had increased five-folds to about 593 MW. The independent power producer owning and operating Olkaria III is the first private company to use air-cooled converters that ensure zero surface discharge. This is a new and most environmentally benign technology in the electricity generation in Kenya. The company sells its electricity to Kenya Power and Lighting Company (KPLC) for nation-wide distribution. It is expected that more independent power producers will participate in the development of geothermal electricity production and that, in the near future, geothermal will be a major energy source in Kenya (see Table 2.8). In Uganda, estimates made several years ago put geothermal potential at about 450 MW located in Uganda's rift valley region but since then a lot of research has been carried out to determine if there is more geothermal potential in the country, particularly in the same Rift Valley which lies along its border with the Democratic Republic of Congo. The search for geothermal sites has kept alive Uganda government's hope of diversifying its electricity generation from the predominantly hydro sources. The areas that, according to geological properties, have shown some prospects include Katwe, Kibiro and Buranga but other areas bordering the rift valley in south-west and northern parts of Uganda also have volcanic and tectonic features that are indicative of possible geothermal occurrence. It has been established that suitable underground rock temperatures ranging from 120 to 200 °C are found in these areas. But, so far, Uganda is yet to exploit the identified geothermal potential. In Tanzania, very little effort has been put on the search for geothermal resources despite the fact that the central portion of Tanzania is in the Great Rift Valley, which is known to have geological formations that are characteristics of geothermal resources. The only exploitation of geothermal resources in the region is done in the Kenyan portion of the same Great Rift Valley [4, 29] .

2.3.4 Coal

Active search for coal has been going on in the region with some mixed expectations particularly in Kenya where efforts are focusing on Mui and Mutito areas in Mwingi and Kitui districts. In Tanzania, commercial coal production started at Kiwira coalmine in Mbeya in the late 1980s with an estimated annual output of about 150,000 tons of raw coal out of which about 93,000 tons of processed coal would be obtained. There is also coal deposit at Mchuchuma in South west Tanzania near the northern tip of Lake Nyasa with a potential to generate 400 MW of electricity for 40 years. Due to the poor quality of Tanzanian coal and the high cost of transportation, coal has not become a major source of energy for domestic application. This has slowed down coal output but it is expected that once coal production is fully developed in the region, it will be used to diversify electricity generation and also supply industrial heat energy requirements not only in Tanzania but also in Kenya and Uganda. It is however not clear whether coal can, in future, make any impact as domestic heat energy source in the region since space heating is not an essential requirement.

2.3.5 Natural Gas

Tanzania was, for a long time, the only country in East Africa where there was proven natural gas reserves with a possible potential of up to 30 billion cubic meters at Songo Songo Island and at Mnazi Bay. The gas can be used to generate a significant amount of electricity in Tanzania and plans are already underway to modify existing thermal generators to use it. Some studies have, however, indicated that operating natural gas-fired generators are too expensive and would raise the cost of electricity. Gas has not made much impact in the national energy scene especially at household level but it has a great potential in electricity generation for the national grid. Given the vast territory of Tanzania and the scattered nature of its towns and villages, both gas and coal resources hold the future for rural electrification aspirations.

The discovery of oil in Uganda and Kenya has changed the situation. Uganda has officially declared the discovery of gas in the country. Kenya is also highly hopeful that some exploitable quantities of gas may be available soon. In Tanzania, the largest gas reserve is at Songo Songo Island in the Indian Ocean, south east of the coastal commercial city of Dar-es-Salaam. Another significant natural gas reserve is at Mnazi Bay. The immediate plan for the gas was to use it as fuel for the existing oil-fired electricity generators in the country and up-grade some of them so that they can feed directly into the national grid network. Of special consideration was the thermal electricity generation in Dar-es-Salaam, particularly the relatively large Ubungo thermal generator (about 112 MW), which was to be converted to use the gas. In order to do this reliably and with minimum transport cost, about 340 km of gas pipeline was to be built to convey the gas directly to a depot in Dar-es-Salaam from where it would be distributed to various electricity generators.

The deposit at Mnazi Bay was to be used in Mtwara town to generate about 15 MW of electricity as well as in Dar-es-Salaam. In addition, the gas was to be used to produce fertilizers for both domestic and export markets as well as liquid fuel substitution in industry and transport sectors. The Tanzanian government agreed with foreign companies through licensing arrangements to handle production of the gas. Normally the exploitation of resources of great values such as this one needs assistance from development partners who prefer a package that includes the participation of more experienced companies. During such negotiation, there emerged a disagreement between the Tanzanian government and a powerful international development partner over the logistical arrangements regarding production and distribution of the gas. This initially caused some delays in completing the planned developments but eventually it was accomplished. Despite its availability in Tanzania, natural gas has not made any significant impact as an energy source. It appears that its use is limited to large-scale power generation and the purpose of this is to reduce national bill for oil importation.

2.3.6 Oil

Oil exploration, both on- and off-shore, has been going on in East Africa for several years and there were strong signs that the region has some significant oil reserves and, indeed, some official declarations have been made to this effect in Kenya and Uganda. Uganda was the first country in the region to officially declare the discovery of oil with an estimated reserves of up to 6.5 billion barrels although recoverable oil may be much less than this; just about 1.4 billion barrels [24]. Kenya is the largest oil consumer in the region and has been importing oil mainly from United Arab Emirates. In 2011, it imported about 51,000 barrels per day of refined oil products and about 30,000 barrels per day of crude oil. This is likely to change as, in 2012, total oil reserves of about 300 million barrels were discovered in Kenya. There are expectations that this will soon top 10 billion barrels mark [30]. This development is not unique to the region as similar discoveries have been made in Ghana and Mozambique. However, since energy is a source of potential conflict, these developments are treated with a lot of caution especially with regard to revenue sharing between stakeholders (counties, national governments and mining companies). Similar exploration activities are on-going in the neighbouring countries of Ethiopia and Somalia while Tanzania is looking to expand its already significant amount of natural gas. One oil company that has been active in the region is a British based company known as Tullow Oil PLC, which also has oil production in other African countries such as Ghana, Gabon, Cote d'Ivoire (Ivory Coast), Mauritania, Congo Brazzaville and Equatorial Guinea. It also has exploration interests in a number of other countries such as Sierra Leone, Senegal, Tanzania, Madagascar, Namibia, Liberia, etc. [8, 10]. All these activities are done under government corporations specifically established to oversee activities in the petroleum industry. For example, in Tanzania, Petroleum Development Corporation (TPDC) is responsible for all aspects of petroleum industry including exploration, production, refining, storage and distribution.

In Kenya, it is the Kenya National Oil Corporation that is responsible for this while Kenya Pipeline Company (KPC) deals with the distribution of all oil-based fuels to major storage facilities. Private sector involvement is also very strong in the petroleum distribution sub-sector and is the main supplier of oil fuels to the end users through region-wide network of petrol/gas stations. Most of these distribution networks were controlled by multinational oil corporations which have, over the years, sold majority shares to local companies in order to consolidate control of local energy issues. There are more than fifteen different oil distributing companies operating in the region with the most prominent being MOBIL, BP, CALTEX, SHELL, TOTAL, ELF, FINA, KOBIL and AGIP. New players have recently joined the market mainly from South and North Africa, and are spreading their networks to cover the whole region. Many of them prefer to enter into the region through Ugandan and Tanzanian markets where competition is not as stiff as in Kenya. Oil-based fuels of various grades (diesel and petrol) are the major sources of energy for the transport sector while kerosene is the main source of power for lighting especially in the rural areas and among the urban low and middle income groups.

2.3.7 Thermal Generators

Being the largest country in the region, Tanzania has experienced more serious electricity distribution problems than the other sister states. As a result of this, the country chose to use thermal generators to power its scattered towns and villages. Some of these are connected to the national grid lines while others are isolated facilities. Those that are connected to the national grid are located in the larger towns and cities and therefore mostly found in Dar-es-Salaam, Mwanza, Tabora, Dodoma, Musoma and Mbeya and are generally operating at about 50 % of their capacities due to management problems. The isolated thermal generators are meant to serve low populated remote settlements and are mainly located in Mtwara, Kigoma, Njombe, Lindi, Tunduru, Mafia, Mpanda, Ikwiriri, Liwale, Songea, Kilwa Masoko and Masai.

The Tanzanian case for these thermal generators is quite unique and was encouraged by the socialist economic policy that Tanzanian government pursued for many years after independence in 1961. The policy encouraged people to get together and live in large communal villages and the government was obliged to support communities' efforts to acquire the basic facilities and this is how small townships got their generators. Many of these generators are facing myriad problems due to old age. Some independent power producers have recently entered into the country's energy sector and they find it more economically convenient to use thermal generators. Consequently, one such power producer, Independent Power Tanzania Ltd (ITPL) is already producing 100 MW, which it sells to TANESCO for distribution. Another one, SONGAS, with a capacity of 200 MW is already supplying 120 MW. This particular company is using the available natural gas in Tanzania for electricity generation. The other independent power companies are the Tanganyika Wattle Company (TANWAT) with a capacity of 2.5 MW and Kiwira Coal Mine with a capacity of 6 MW. Both of them are using thermal generators.

Like Tanzania, Kenya has a number of thermal generators. The majority of them are managed by the Kenya electricity Generation Company (KEGEN), which sells power to the distribution company, Kenya Power and Lighting Company (KPLC). The largest of these is the Kipevu system located at the Indian Ocean coastal city of Mombasa. The system uses three different methods of generation: thermal, diesel engines, and gas turbines. The first Kipevu thermal machine was commissioned in 1955 and was gradually up-graded to seven machines by 1976. These were oil-fired drum type boilers. The first five machines have been retired due to aging while the last two machines are still operating with a total capacity of 63 MW. The first Kipevu gas turbine was commissioned in 1987 with an installed capacity of 31 MW while the second one with a capacity of 32 MW was commissioned in 1999, bringing the total gas capacity to 63 MW. The Kipevu diesel generator was commissioned in 1999 with an installed capacity of 73 MW. Up in Nairobi, there is yet another gas turbine, which was commissioned in 1972 with an installed capacity of 13.5 MW at Nairobi South. All these are connected to the national grid network but there are also three isolated thermal generators serving remotely isolated towns. These are the Garissa Power Plant with an installed capacity of 2.4 MW and supplies power to Garissa town in the remote part of North Eastern Kenya; the Lamu Power Plant that supplies electricity to the traditionally unique Lamu Island; and the Marsabit thermal generator. Marsabit is an isolated town in the northern part of Kenya where security risks make it difficult to manage grid power lines. There are a few independent power producers using thermal generators such as Tsavo Power Ltd, which has an installed capacity of 74 MW. There are also other thermal power generators in Lanet (55 MW), Eldoret (55 MW), Embakasi (105 MW) and Ruaraka (105 MW).

The other state in East Africa, Uganda, gets most of its electricity from hydro power stations. Electricity from thermal systems is still small but this is set to grow given that Uganda has discovered a significant amount of oil. However, electricity production in Uganda is much lower than in either Kenya or Tanzania. The recent reforms in the power sector are expected to attract some independent power producers who generally prefer to use thermal generation methods. When this happens, then Uganda is likely to increase its capacity in thermal electricity production. The present political will to bring the three East African states closer together may encourage more thermal generators based on coal and natural gas produced in

Tanzania. Kenya government has put up an elaborate plan to increase electricity generation to over 5000 MW by 2017 and there are indications that this will be done by using coal (about 1900 MW), geothermal (about 1600 MW) and natural gas (about 1000 MW) while wind is expected to contribute about 600 MW [8, 10]. It is expected that as more natural gas and oil are discovered in the region, East Africa will lean more towards thermal plants for electricity generation.

2.3.8 Co-generation

Cogeneration is a system in which both electricity and process heat are produced from the same power plant. It is also often considered as a process in which electricity is generated as a secondary commodity in addition to the core product of the establishment. For example, timber mills need electricity to operate while at the same time they produce a lot of wood waste that can be used to produce that electricity. Similarly, sugar factories need electricity but, to produce sugar, they need a lot of heat for their boilers, and this heat is obtained by burning sugarcane waste (bagasse) and the steam from the boilers can be used to turn turbines for electricity generation. Thus their core product is sugar but they find it also convenient to generate electricity for their own use since steam is available. This technology is globally proven and indeed many of these factories have been doing just that for a long time but the laws governing the power sector did not allow them to produce electricity as a commercial commodity. This has been a very unfortunate situation in countries where surrounding communities still rely almost entirely on biomass as the source of energy. Thus cogeneration, attractive and cost-effective as it may be, has not been exploited in East Africa for the benefit of the communities.

In Tanzania, cogeneration has been practiced at sawmills such as Sao Hill and Tanganyika Wattle Company and also at sugar processing plants such as Tanganyika Planting Company Ltd (TPC), Kilombero Sugar Company, Mtibwa Sugar Estates and the Kagera Sugar Company. A few of these like the Tanganyika Wattle Company (TANWAT) are already making use of the reforms to sell power to Tanzania Electricity Supply Company (TANESCO) for national consumption. There is, however, a growing interest in producing electricity as part of the commercial outputs with a view to selling it in order to improve economic performance.

In Kenya, there are also a number of sugar milling factories and other agro-based companies, which have the capacity to increase their cogeneration levels but have not made any significant contribution in the supply of electricity to the public. These are Sony Sugar, Nzoia Sugar, Mumias Sugar, Chemelil Sugar, Muhoroni Sugar, Agrochemical and Food Company and the Spectre International Plant (formerly Kisumu molasses plant). All these companies are located in western part of Kenya and are capable of supplying the region with a substantial amount of electricity. They are all close to Lake Victoria and together with other sugar companies such as Kagera Sugar Company in Tanzania and Kakira Sugar Company in Uganda, which are also close to the lake, could effectively serve much of the

Lake Victoria region with electricity. Already, by 2013, Kakira had prepared to increase its electricity generation capacity to over 50 MW with the aim of selling the surplus to the Uganda Electricity Board. It was also planning to diversify its production to include ethanol which is to be used for blending transport fuel.

The desire by these companies to actively co-generate electricity for commercial distribution is a progressive development that should be encouraged by the respective East African states. The seven sugar milling companies in Kenya produce an average of about 1.8 million tons of bagasse. Out of this, about 56 % is used in cogeneration with an average capacity per factory of 25 MW, which is all consumed in-house. The rest of the bagasse is disposed at a cost to the company. With some incentives and appropriate energy policy, the bagasse can be used to generate more electricity that would bring additional income to the company and also increase national electricity generation capacity. In Kenya, Mumias Sugar Company recently upgraded its energy production by about 38 MW some of which is sold to Kenya Power and Lighting Company. It further diversified its production by establishing an ethanol plant for producing ethanol fuel, which can be used to blend gasoline (about 10 % ethanol and 90 % gasoline) and reduce expenditure on imported petroleum fuels. Other sugar companies are planning to do the same. However, it is not clear what would happen to these plans in the wake of oil discoveries in the region.

Cogeneration is one of the methods of generating electricity that have the best chance of success in the region particularly in rural electrification efforts.

These industries use bulky agricultural products as their principal raw materials and therefore, to encourage farmers to grow these inputs, transport cost must be kept as low as possible so that both the industry and the farmers can mutually benefit. For this reason, the industries are normally located in the rural areas close to the sources of raw materials. Their potential to generate electricity as independent power producers can be further developed with little additional investment since most of them are using the by-products of the raw material to produce small quantities of electricity. Another important aspect is that the government can plan and choose the right location for the establishment of such factories so that rural electrification plans are also addressed besides the core function of the companies. The companies also benefit by selling both energy and the core product instead of just one commodity. Thus the companies would afford to lower the prices of both power and the core commodity and still make enough profit. The potential for cogeneration is high and the prospects are very good for the companies. East Africa has a number of agro-based industries that could supply electricity to their neighbourhoods if suitable power legislation and regulatory arrangements are put in place. The area that could benefit most from the cogeneration is the Lake Victoria region of East Africa where there is a high concentration of agro-based industries, which have been producing electricity for their own use. One of such factories is located on the shores of Lake Victoria (Fig. 2.15). There are about eight large sugar factories and at least five allied industries (molasses and paper industries) around Lake Victoria whose energy outputs could make a significant contribution in the development of the region (Fig. 2.16). The potential for electricity generation from

Fig. 2.15 Molasses plant owned by spectra international at the Lake Victoria city of Kisumu

Fig. 2.16 A sugar factory in Lake Victoria region

Table 2.15 Examples of cogeneration capacity in Tanzania [32]

Power plant/company	Capacity (MW)
Kagera Sugar Company	5
Mtibwa Sugar Estate	4
Kilombero Sugar Company	3.4
Tanganyika Planting Company	20
Sao Hill Saw Mill	1
Tanganyika Wattle Company	2.8 (already selling power to TANESCO)
Total capacity	36.2

bagasse within the Kenyan side of Lake Victoria basin is estimated to be about 300 MW but could be more than this if the factories are upgraded to higher production capacities. The exploitation of such capacity in the region would significantly improve the diversity of national power supply and also lower the cost of products from these factories. Table 2.15 gives some examples of cogeneration capacities in Tanzania. Most of the companies can upgrade their capacities and are indeed planning to do so in order to take advantage of the new energy policies.

The capacities indicated in Table 2.15 are based on the energy requirements for the companies but they have greater potential than these and can be up-graded to much higher capacities within the present operational limitations. Co-generation therefore has a great potential in the region particularly the central part of East Africa (Lake Victoria basin), which has a significant cogeneration potential. In general, however, the distribution of co-generating facilities in the whole region and possible choices of the locations of the new ones make them appropriate centres for rural electrification programmes.

2.3.9 Portable Generators

Large fuel fired generators are the most attractive electricity generation facilities for independent power producers even though they are more expensive to operate since they require specific fuel inputs. About 90 % of the population of East Africa has no access to grid power and there are arguments that even if they had, it is unlikely that they would use it. This is partly because of the high level of poverty amongst the rural communities that force them to live under conditions that would be even more dangerous with electricity supply and partly due to policies that suppress demand. So the issue of electricity is not a simple problem of lack of access and high cost but also a social issue as well. The use of thermal generators therefore will not help in bringing the cost of electricity to affordable level for the rural population. However, the prospect of ownership and personal control of application and running cost is an important feature for rural farmers who periodically receive large incomes and can afford to buy portable generators. So the potential for small portable fuel-operated generators that can supply enough electricity to a household is definitely available in the region. A number of these are already in use despite their high operational costs and purchase prices. They are usually used only when necessary, for example, to light a wedding, funeral or an important social function. Their widespread use will depend on how low their prices will go but currently this is the option taken by the few medium and high-income groups in the rural areas. But even for these groups the use of generators is limited to special occasions.

2.3.10 Biomass Energy

When talking about biomass energy, we refer to energy obtained from direct combustion of any form of vegetation (wood, grass, shrubs, agro-waste, sawdust, sugar cane bagasse, etc) including their gaseous, liquid and solid products like methane (biogas), bio-diesel, producer gas, ethanol (power alcohol), cow dung, and charcoal. Some electricity generators, the so-called thermal generators, use heat from biomass to produce high pressure steam that turns the turbines. The cogeneration discussed in the previous sections use heat obtained directly from biomass combustion. Some biomass materials such as sugarcane can be converted through fermentation into ethanol (also known as ethyl or power alcohol), which in turn can be used to blend oil-based fuels in order to reduce the consumption of oil particularly in the transport sub-sector. This method can help in reducing the amount of convertible currencies that poor developing countries spend on importation of oil. Furthermore ethanol can be used in a variety of industrial productions such as chemical, pharmaceutical and beverage industries. East Africa is often overburdened by expenditures on oil imports when oil prices suddenly go up due to political turmoil in the oil producing countries. For this reason, the possibilities of producing ethanol from raw sugarcane or molasses and mixing it with oil for use in conventional petroleum powered machines and transport vehicles have been studied and prototype production schemes carried out. Biomass is therefore the most interesting energy source especially in the developing countries where most people including their governments are too poor to afford other sources of energy, which may not even be locally available. On a smaller scale, biomass can be converted into combustible gas known as biogas (methane) that is used for both cooking and lighting. In East Africa, biomass, in its various uses, accounts on average for more than 80 % of the total energy consumption and almost the entire rural population in the region depends on biomass energy for energy supply mainly in the form of dry wood, also known as fire wood.

One most important aspect of biomass materials is that, practically, most countries of the world can produce it in large quantities and this is part of the reason why it is such an important source of energy for rural communities in the developing countries; they have access to it and it is possible to generate it in any desirable quantities. In addition to energy, biomass is also used for many other purposes such construction of buildings and furniture and therefore it is generally in high demand. Fortunately these other applications require high quality wood while for energy applications low quality biomass such as dry branches of trees and other wood wastes are quite suitable. This means that wood fuel can be obtained from live trees without having to cut down the whole tree. Consequently the various uses are usually not viewed as competitive.

The second interesting characteristic of biomass as an energy source is that it does not require special and complicated cooking devices (stoves) and traditionally the users, who are mostly women, design and construct the cooking place. This may be a simple arrangement of three stones between which wood is burnt or suitably dug-out shallow oval holes in which biomass is burnt. The cooking pot is either supported by the three stones or is placed above the hole. More recently a number of portable improved wood stoves have been developed and disseminated amongst the East African rural communities including schools and colleges. A fast-growing consumption technique is the conversion of woody biomass materials into charcoal, which is easy to store and transport. It is also consumed in smaller quantities than wood and is therefore most preferred by those who do not have space to store wood especially the urban middle and low-income groups. These groups together with the rural communities constitute more than 90 % of the total population of East Africa.

A large potential exists in the generation of biomass materials and also in the development of biomass energy devices like cooking stoves that can use various forms of biomass such as briquettes of different biomass materials such as sawdust, charcoal dust, fallen dry leaves, rice and coffee husks [21]. Considering the number of people that use biomass as a source of energy and the important role played by biomass in producing other forms of energy, we see that biomass is such an important source of energy that should not be ignored in any rural energy planning process. Given that the situation regarding the present types of rural shelters, the level of poverty and the eating habits are not likely to change in the near future, biomass development must be seriously considered as an integral part of the energy systems. Its most important feature is the fact that it can be converted to commonly used forms of energy (heat and electricity) and also to gaseous and liquid energy sources such as biogas, producer gas, and ethanol. The level of these conversion technologies may be low in East Africa at present but there is great potential for their development. Production and use of charcoal, which is a high heat content biomass fuel, is well established in the region but the people need to be trained to develop and use efficient wood-to-charcoal conversion technologies. The general climate is also quite suitable for biomass regeneration programmes. Production of ethanol from biomass has been considered in Kenya as one possible way of reducing oil imports. This possibility was seriously considered in the 1970s when the oil crisis adversely affected the economies of East African states. At that time Kenya, for example, was spending as much as 35 % of her total import bill on importation of oil. The idea that ethanol, produced from sugar cane, could be added to the imported oil and used to power existing vehicles without any engine modification gave Kenya some hope of reducing her expenditure on petroleum. A reasonable ratio of petroleum-ethanol mixture was expected to reduce the amount of imported oil by about 20 %. Two alternative production methods were studied: one was to produce ethanol from molasses generated by the existing sugar mills in western Kenya and the other was to produce ethanol directly from sugar cane. The former was considered more economically viable since there were active sugar milling factories that could supply molasses to the ethanol plant. Two ethanol plants were therefore established within the western Kenya sugar belt: the Agro-Chemical and Food Company in Muhoroni and Spectra International formerly known as Kisumu Molasses Plant. Apart from ethanol, these plants were also designed to produce other products of commercial value from the same molasses.

East Africa has several active sugar milling factories that can adequately support ethanol production. However, the economic analyses on local ethanol production showed that using the technology adopted by Agrochemical and Food Company at Muhoroni in western Kenya is more costly than imported gasoline. Thus ACFC can only make profit if the produced ethanol is exported. But there are possibilities of reducing the cost of production to an economically viable level. Improvement of production efficiency can be made in areas such as fermentation, distillation, use of self-generated energy, and acquisition of cheap or free molasses. This together with more cost-effective management arrangements would definitely make ethanol cheaper than imported gasoline. But, at the moment, these companies are facing very challenging economic issues and are struggling to keep afloat. Therefore diversification of production to include other services is necessary in order to substantially bring the cost of ethanol down and also ensure that there is enough income for these companies to continue their operations. This is an option that is feasible in East Africa and should be given some in-depth consideration since there are a number of sugar milling companies that have the capacity to also commercially co-generate electricity for public consumption. Thus the potential for biomass embraces a wide range of processing options from solid to gaseous fuels. The region however has no experience with bio-diesel although the potential for its development from locally grown crops exists. Research and development in this area should be considered and supported as a long-term energy plan for the region.

For a long time, biomass was so easily available in the immediate neighbourhood that it could not be imagined that one could buy it for use as an energy source. Today, much of it has disappeared and wood fuel is now a commodity that one can buy in the local markets even in the rural areas. Fuelwood demand in Kenya is 3.5 million tons per year while its supply is 1.5 million tons per year. The massive deficit in fuelwood supply has led to high rates of deforestation in both exotic and indigenous vegetation resulting in adverse environmental effects such as desertification, land degradation, droughts and famine [3, 11]. It is, however, still very cheap compared to other energy resources and most people can still obtain it without having to buy it. It is also a very interesting energy source and many energy specialists still find it difficult to quantify wood in terms of energy quantity since it does not have standards or set properties for accurate determination of its energy properties. In addition to variations of wood species, wood can have different energy values depending on its moisture content. Although water in the wood may not have heat value, it nevertheless reduces the net heat value of the unit weight of the wood since it has heat capacity and latent heat of evaporation that must be supplied from energy in the wood when the temperature is raised to a combustion level. So the energy of the wood falls rapidly as moisture content increases. Table 2.16 gives examples of variation of heat content in wood as a function of moisture content. Wood is also bulky with weights that depend on the moisture

Table 2.16 Energy values of wood and wood products [29]

	Moisture content	Energy content MJ kg^{-1}
Wood	100–120 %	8.3
	15–20 %	16.4
	8–10 % (bone dry)	19.3
Charcoal	5–10 %	29
Wood gas	–	7

content and therefore its transport cost is generally high compared to the amount of energy obtained from it. Charcoal, which is produced from wood, contains about 50 % of the energy in the original wood, weighs only about 25 % and has more consistent properties than wood. Its calorific value is comparable to those of some industrial grades of coal. These qualities make it a popular source of energy for low-income urban population who do not have much storage and cooking space. In addition to its high energy content, charcoal also has the advantage that it does not burn with much flame that could cause any danger or discomfort to the user; it simply glows and produces the required heat. On the one hand, the negative side though, the carbon monoxide gas that is produced from burning charcoal poses the potential danger to its users. Some people have died from using charcoal in poor ventilated houses. On the other hand, the CO_2 produced in using charcoal contributes to the greenhouse gases known to increase global warming.

The level of biomass contribution to the total national energy consumption in Kenya has gone down to about 70 % from about 82 % level of the 1980s. In Uganda and Tanzania, it is still contributing about 90 % of the total energy consumption. This is a direct indication that the urban population in the region is still a very small fraction of the total population. The low consumption level of biomass in Kenya could be attributed to the fast growing number of the so-called rural market centres where small traders settle to carry out their businesses. Residents of such centres tend to rely on kerosene for both cooking and lighting. As discussed in chapter one, these centres also normally spring up faster along national grid power lines. So some successful traders use electricity and LPG as their domestic energy sources. The main factor, however, is the high growth rate of urban population of young people in search of job opportunities. It is now estimated that about 30 % of Kenya's population is urbanized. Kenya is also more economically developed than either Tanzania or Uganda and this explains the relatively higher per capita clean energy consumption and lower biomass use compared to Tanzania and Uganda. It is nevertheless clear from Tables 2.5, 2.6 and 2.7 that almost the entire rural population in East Africa depends exclusively on biomass energy resources. This also implies that although it is becoming more and more difficult to obtain, biomass is still available in sufficient quantities to satisfy the demand. Many people are aware of its crucial value as an energy source and are making efforts to plant various types of trees for this purpose while at the same time using plant residues as energy source. Individual forestry master plans for Kenya, Uganda and Tanzania indicate that wood resources are on the increase in farms while they are decreasing in other land categories. This shows that the ordinary people are aware of the importance of biomass regeneration to the extent that tree planting is readily accepted practice in the farms. The popular tree species planted in the farms include *Grevillea robusta*, Eucalyptus species, Cypress species, and a variety of fruit trees [13–15, 20, 35, 36].

The fast growing population of the region is constantly increasing the demand for wood-fuel so that forests are consumed much faster than they are regenerated. During the last three decades, deforestation for wood fuel has been a major concern for most non-governmental organizations. Subsequently, they have undertaken several activities to redress the situation. These include: improved charcoal stoves, wood and sawdust domestic stoves; institutional stoves; energy conversion technologies such as wood-to-charcoal; rice husks to charcoal briquettes; animal dung to biogas and solid biomass to gas. Some of these activities have been reasonably successful. For example, the Kenya Ceramic Jiko (KCJ), a technology adapted from Thailand, which was first introduced in Kenya has successfully spread to Tanzania, Uganda, Ethiopia, Sudan and even Rwanda and Burundi.

One aspect of biomass energy, that has not received sufficient attention, is the extraction of fuel-oil from energy crops. Research in this area will be important especially if the research for direct substitutes for fossils oil is to continue.

Biogas, also classified as a product of biomass materials, has also been researched into and developed. Although biogas plants are advantageous in that the by product is useful as soil fertilizer, the technology has not been successfully implemented on a wide scale. The initial investment cost is high and it requires qualified manpower and constant attention in order to operate efficiently. Tanzania has however demonstrated that some of these constraints can be overcome. But further work is required to explore the possibility of commercializing the gas instead of the plants.

In the following sections, a detailed account of biomass in Uganda is given as an example of what is happening in the East African region.

2.4 Biomass Energy in Uganda: An East African Model

Biomass energy strategies in the East African states are basically similar with only minor variations in the level of emphasis and implementation of some specific areas. In fact the similarities can also be extended to other Sub-Saharan African countries. We therefore consider in details the situation in Uganda as a representative case for not only East Africa but also for wider region.

2.4.1 Uganda's Biomass Energy Policy

In 1999, the Ministry of Energy and Mineral Development (MEMD) of Uganda began a process of formulating a new policy for the energy sector under the National Energy Policy. This energy policy is unique in that it includes a section on biomass energy. Revision of the Forest Policy began in 1998. Both the new and old policies attempt to address biomass issues. The Forest sector has gone further to develop a National Forest Plan, which is complementary to the National Environment Action Plan.

The National Biomass Study (NBS) of the Forest Department has collected data on biomass distribution throughout the country since 1989. This information is useful for planning for biomass supply and includes information on crop distribution and acreage and livestock stocking rates, which can be used to establish how many agricultural residues are available for energy production. It should be noted that use of agricultural residues for energy production should not in any way compromise its priority use as a natural fertiliser since the average farmer in Uganda cannot afford commercial fertilisers.

The MEMD has developed strategies for rural electrification, petroleum supply and energy efficiency. Despite the importance of biomass in the national energy balance accounting for 93 % of total energy consumption, there is no comprehensive biomass energy demand strategy. Wood is the predominant source of energy for domestic cooking and for process heat in the industrial and institutional establishments. Charcoal production and consumption is an important part of the economy supplying most urban areas with cooking fuel and generating about 20,000 full time jobs. Due to the high rate of consumption, it is believed that biomass resources are being depleted at a higher rate than production but data are insufficient to prove this view. In addition, land under biomass production is regularly converted to farmland, which is sometimes devoid of trees. The MEMD and other actors have implemented isolated biomass projects.

This strategy attempts to synchronize the energy strategies in the energy policy, the national forest plan and the national environment plan. The proposed biomass energy strategy has been formulated on 6 major principles namely:

- Institutional aspects;
- Human resource development;
- Mobilising financial resources;
- Dissemination of awareness;
- Quality control; and
- Research.

The 1995 Constitution of Uganda recognises the need for an energy policy oriented to the poor when it states “The State shall promote and implement energy policies that will ensure that people’s basic needs and those of environmental preservation are met”. The importance of energy for the poor and the development of Uganda is recognised in the revised Poverty Eradication Action Plan (PEAP) of 2000. Energy has a direct impact on poverty alleviation. Improved electricity supply is expected to enhance poverty alleviation initiatives through both the promotion of private sector driven economic growth and via direct poverty impacts. The link between energy and the introduction of new technologies for agro-processing in the rural areas is especially relevant to government’s Plan for Modernisation in Agriculture. PEAP also highlights the link between energy and basic needs and notes that the dependence on fuelwood increases the burden on women and cause environmental degradation. It further notes that the first step in climbing the energy ladder is the use of improved cooking technologies and the introduction of more efficient methods for charcoal production.

About 93 % of the energy consumed in Uganda is from biomass, which includes wood, charcoal and agricultural waste. 95 % of wood supply is for energy consumption with the following characteristics:

- Wood is the only energy option for the poor since only about 1 % of the rural population has access to electricity (2000 estimate).
- Scarcity of wood affects nutritional value of food cooked as it limits the type of food and level of cooking and therefore many people strive to ensure that it is available all the time.
- Wood is a renewable energy if its regeneration and consumption is planned sustainably.
- Wood is a major source of process heat in industries and is therefore of important economic value for the nation in addition to its direct use as construction material.

These characteristics confirm that wood will continue to be the dominant source of energy in Uganda for many years to come even if the entire hydro potential in Uganda is to be fully utilized. One major concern is that Ugandan households generally use biomass energy inefficiently. The application of improved wood stoves and other energy sources (LPG, solar energy, kerosene and electricity) is limited in most areas. A few institutions such as schools have converted from open fires to improved cooking stoves. A few high-income households and expatriates us LPG and electricity for cooking.

In Kampala, the market efficiently supplies the consumer with a steady, uninterrupted supplies of fuel wood and charcoal at relatively low prices. However, these low prices are below their economic cost, due to the fact that fuel wood taxes and fiscal compliance rate are low and that so much charcoal is coming into urban areas as a result of rapidly increasing land clearing for grazing and agriculture. This is also confirmed in Mbarara Town where the price of the charcoal bag has reduced from Ush 12,000 to 8000 (about USD 6.5–5) following an increase in the number of charcoal traders especially the wholesalers using lorries. Thus economic incentives to conserve wood and charcoal have diminished over the past five years due to increased demand. The taxation on wood fuel serves no regulatory objective. That means that price of financial incentives to purchase more energy efficient stoves diminished.

2.4.2 Overall National Energy Policy

The energy sector has historically placed emphasis on policies that address supply of commercial sources of energy, giving little attention to biomass, which is the major source of energy in the country.

The main goal of the new National Energy Policy is to meet the energy needs of the Ugandan population for social and economic development on an environmentally sustainable way while the second objective is to increase access to modern affordable and reliable energy services as a contribution to poverty eradication. On the demand side the main objective for households and community is the provision of basic services including water supply and sanitation, health, education, public lighting, and communication in order to improve the social welfare of the rural population.

The specific objectives for this sector are to:

- Achieve a sustainable level of energy security for low-income households so as to reduce poverty at household level;
- Improve the efficiency in the use of biomass resources, recognizing that biomass will remain a dominant source of energy, especially in the rural areas, for the foreseeable future;
- Specifically target provision of energy to productive activities such as home-based industries in order to directly raise household incomes; and
- Sensitise women on energy source and technology choices in order to reduce the labour, burdens and poor health conditions associated with biomass energy use.

The National Energy Policy recognizes the role energy supply improvement in rural areas is likely to play thus the need to include biomass in the realms of national energy planning.

It also recognizes that wood fuel harvesting contributes to degradation of forests as wood reserves are depleted at a rapid rate in many regions, the impact on the environment, health of end-users and the burden of collecting firewood on women and children as a result of increased use of biomass energy. In some parts of the country wood fuels are now scarce. This could be addressed to some extent through demand side management, which includes the use of energy efficient devices and alternative sources.

There is insufficient data on demand and supply of biomass fuels in the country and lack of awareness about the potential for biomass energy technologies. The policy views reinforcement of database on biomass especially the demand factors as a major thrust for planning purposes.

The policy recognizes the inadequacies within government institutions to plan for and monitor the sub-sector, and conduct research and development. The energy policy plans to increase private sector participation through use of smart subsidies particularly for improvement in efficiency and technology acquisition. Emphasis would be placed on improving efficiency of biomass use along the production to end-use chain.

The energy policy proposes strategies to address demand side in various sectors namely household, institutional, industrial, commercial, transport and agricultural sectors. Energy efficiency is the major thrust in demand side management. In addition the policy proposes strategies to address supply sub-sectors namely the power sub-sector, the petroleum sub-sector and the biomass and other renewable energy sub-sectors. The major objective of the biomass and other renewable energy strategy is provision of focused support for the development, promotion and use of renewable energy resources for both small and large-scale applications.

2.4.3 Forestry Policy and the National Forest Plan

Uganda's forests and woodlands are viewed as the mainstay in the three pillars of sustainable development; industry, society and the environment. The forest policy recognizes that Uganda's forest resources provide energy, supplying 93 % of national energy demand.

Gazetted forest reserves, which cover about 40 % of total forest area in the country, are not the major sources of biomass energy for current and future demand. About 35 million cubic meters of firewood are consumed annually. This is way above the total annual allowable exploitation of 350,000 m^3 for all reserved forests. Since these forests still have growing stock, it implies that the bulk of biomass used for energy is mainly obtained from areas outside forest reserves. However, it is not documented as to how much of this quantity is supplied by gazetted forests.

The forest policy views farm forestry as major strategy in ensuring adequate supply of biomass energy. The role of the forest sector would be the provision of adequate, clean seed and advisory services to extension officers based at sub-county level. The planned extension service under National Agricultural Advisory Services (NAADS) is an effective way of reaching subsistence farmers thorough out the country. The policy also plans to take advantage of governments' commitment to promote and develop farm forestry through the Plan for Modernization of Agriculture.

The use of forestry waste as a source of energy is not addressed but is implied since there are no planned energy plantations and so forest reserves are expected to supply some fuelwood as outlined in the National Forest Authority Business Plan. The tops and branches from logging operations would be sold as wood fuel. This wood fuel would be obtained from processing cycles as stipulated in the management plans for specific forest reserves.

The forest policy mentions collaboration with stakeholders such as poor rural and urban population, those working in wood industries, consumers of forest products, servants of the sector and the wider national and international public but no clear strategy is highlighted. Further, the policy specifies collaboration with the agriculture, land use, water, wildlife, industry and energy sectors.

2.4.4 Availability of Woody Biomass

The data on biomass supply assumes that all the biomass is accessible to the population. In reality, a lot of the biomass held in forests is either inaccessible due to long distance or because of management restriction in protected areas such as forest reserves, game reserves and national parks. For purposes of simplicity, if areas under protection are assumed to be unavailable or inaccessible, then the available supply of biomass for use shall be reduced drastically to about 50 % of the total biomass available.

Sources of wood used for firewood and other forest products can also be derived from these distribution patterns and land use types. For example the nearest source for fuelwood would be the subsistence farmland areas or the nearby bushland areas.

2.4.5 Agriculture

Biomass energy from crops is derived from agricultural residues arising from growing and harvesting of both food crops and cash crops. The most common food crops grown in Ugandan are: Plantains, both green and sweet bananas, finger millet, maize, sorghum, rice and wheat, root crops such as sweet potatoes, Irish potatoes and cassava; beans, field peas, soya beans and pigeon peas; others are groundnut (sometimes called peanuts), and simsim. The cash crops grown are coffee, cotton, tea and sugar cane. The distributions of these crops in the country depend on specific crop requirements such as soils and climatic conditions (e.g. rainfall patterns and its distribution). The following section presents the areas and production of the major crops in Uganda based on data from the Ministry of Agriculture (1995).

2.4.6 Agricultural Residues (Food and Cash Crops)

Agricultural residues are the materials left after harvesting or processing of crops. Data on residues are in most cases lacking. Therefore, the data for residues were derived by calculating the production figures of each crop with appropriate conversion factors (residue-production rations). The total agricultural residue is about 8,000,000 tons of which about 1,734,000 tons is available for energy use.

2.4.7 Livestock

There has been no recent detailed livestock census carried out in the country. Thus the figures given are derived from the Ministry of Agriculture, Animal Industries and Fisheries statistical abstract 2000. It was estimated that there were about 5000 cattle, 900 tons of dry matter per year of which about 240 tons is available for energy use.

2.4.8 Total Biomass Production and Use

The overall potential stock of woody biomass in Uganda in 1995 was about 477.2 million tons air dry. However if the biomass from protected areas were removed from the gross national stock, the net available stock would be reduced to 275.9 million tons air dry.

It should also be noted that in reality only small stems, twigs and branches are normally utilized. If this is taken into account, the available stock would be further reduced to about 30 % (about 90 million tons of wood).

The total sustainable biomass production and consumption flows have been summarized at national level but the information is so sketchy that it cannot be used for effective planning. The concept of sustainability is that the annual consumption should not exceed the mean annual increment. The annual gross sustainable yield at national level is about 20.4 million tons per year. However if the available supply from non-protected areas is considered alone, then the yield will be reduced to about 14.5 million tons per year.

As expected from the above presentations, the highest biomass supply was from trees (14.4 million tons per year, air-dry biomass above ground), followed by agricultural residues (1.7 million tons per year) and the rest were from animal wastes.

On the consumption side, firewood consumed by household constitutes the greatest amount of biomass, followed by charcoal, firewood for commercial purpose and residues. Only 50 % of crop residues available for energy purpose are consumed. An increased supply from this source should be considered with care.

The data on land cover (use) distribution, areas, standing stock (biomass density), agricultural crop areas and animal waste production were used to quantify the supply of biomass while data on charcoal and firewood from available literature were used to determine the quantity of biomass consumed in 1995.

On the supply side, Uganda had a total stock of 4772 million tons of woody biomass in 1995. The total biomass yields were about 20.4 million tons per year of wood (annual mean increment), 8.0 million tons per year of agricultural crop residues and 4.7 million tons per year of animal wastes.

The available (excluding protected areas) amounts for energy use were 275.9 million tons of wood as stock, 14.46 million tons of wood per year, 1.73 million tons of residues per year, and 236,000 tons of animal wastes as yields.

On the consumption side in the same year, a total of 20.2 million tons was consumed of which nearly 80.5 % was firewood, 14.5 % charcoal, and 4 % residue.

Biomass flows based on these sustainable yields gave a negative balance of 3.8 million tons per year in 1995. The deficit for woody biomass is even higher: 4.9 million tons per year for the same year.

Some gaps exist in the data and the estimates of the above biomass should be treated with caution since many issues that affect the gross supply and the consumption were not factored in. Nevertheless, the general conclusion is that with a negative balance of 3.8 million tons, there are serious challenges to the sustainable use of this resource. In certain regions and districts, the situation is even worse.

Under the present circumstances, the future biomass supply for Uganda cannot be guaranteed. This is because the demand for biomass resources would intensify as the population increases. Remedial actions have to be put in place before the situation worsens.

2.5 Some Biomass Energy Challenges

This section reviews some biomass energy initiatives in Uganda and examines some of the barriers to dissemination of Biomass Energy Technologies (BET). The initiative mainly cover creating awareness and dissemination of technologies for tree planting and energy efficiency, particularly improved stoves and improved charcoal production techniques. There are some activities addressing capacity building as well. Most non-governmental organizations (NGO) and public sector initiative receive donor support while private sector activities are supported by the parent companies.

The Ministry of Energy and Mineral Development (MEMD) with support from development partners is implementing the Sustainable Energy Use in Households and Industry (SEUHI). The objective of the project was to improve efficiency in energy conversion and use in the households and small-scale industry. The project address rural and urban household stoves in Kampala, Soroti, Adjumani, Kabale and Tororo; charcoal production in Luwero, Nakasongola and Masindi; and lime production in Kasese, Kisoro and Tororo.

The MEMD has:

- Disseminated improved cookstovesin 34 sub-countries in the districts of Kabale, Tororo, Soroti and Adjumani. Over 400 people have been trained and about 7000 households now use improved stoves.
- About 70 artisans were trained in production and marketing of improved charcoal stoves in Kampala and Kabale.
- Over 130 charcoal producers in Nakasongola, Luwero and Masindi Districts were trained in improved charcoal production methods.
- Three charcoal producers associations were formed.
- Two charcoal producers associations benefited from a modest revolving fund through association's access to Kampala markets. The two associations have been operating stalls in Wandegeya and Namasuba Markets since August 2000.
- An improved limekiln in Tororo was completed and launched and another lime kiln was built in Kisoro.
- Energy audits have been carried out in some biomass-based industries.
- Eight tree nurseries were established in sub-counties in Kabale District.
- In collaboration with some agro-based institutions, MEMD planted over 500,000 seedlings in Adjumani District.
- Provided facilitators to Nyabyeya Forestry College on energy issues.
- Established 20 biogas digesters and trained 20 artisans in biomass digester construction.

Under the Energy Advisory Project supported by a European development partner, MEMD prepared the national energy Policy, sub-sector-strategies and energy Information System. Technical assistance was also provided to different NGO projects and the media. A Biomass Energy Development Programme (BEDP) was prepared. The MEMD plans to remove barriers to increase biomass energy efficiency in households and small-scale industries in rural and peri-urban areas. This will be done by promotion of improved technologies, energy saving methods, and fuel substitution. High priority will be given to urban households, institutions and small industries where management and motivation to cut fuel costs would quickly settle in.

Biomass is used to supply energy for a number of activities. Some of these such as tobacco curing encourage the users to also plant trees as they consume available biomass materials. Several local NGOs and groups, such as Joint Energy and Environment Project (JEEP), Integrated Rural Development Initiatives (IRDI), Renewable Energy Development Centre (REDC), and learning institutions have collaborated with various international development organizations to promote tree planting and use of efficient energy devices.

2.5.1 Information Deficiency

There is lack of comprehensive and reliable data especially on the consumption side. Biomass energy planning relies on a wide variety of information (both quantitative and qualitative) from different disciplines. The responsible institutions such as Energy Department and National Bureau of Statistics are chronically handicapped by financial and human resources and usually occupy a marginal role in the national planning context. Even basic data such as the prices of wood fuel in different parts of the country may be missing or inconsistent. Quite often, the discrepancies among independent estimates illustrate the low consistencies and reliability of data sources, with obvious negative consequences for formulation or identification of priorities and definition of policies and strategies. The figures and facts about the central role played by the sub-sector in term of offering employment or its contribution to the country's GDP are not documented. If valid arguments are to be won in favour of the sub-sector, say for more resource allocation, facts and figures should obviously back such an argument.

2.5.2 Technology

The sub-sector is characterized by few producers/manufactures of proven Biomass Energy Technologies (BET). A large number of manufacturers produce items of low quality and sometimes worse than "traditional" technologies in terms of efficiency, durability and other attributes. There is lack of knowledge about the availability of new technologies, and the advantages and constraints associated with such technologies. Advanced biomass technologies such as gasification, and modern brick kilns are little known in the country. There is clearly lack of quality control and regulation in the sub-sector.

2.5.3 Institutions

The key institutions in the biomass sub-sector including MEMD, NGOs and private companies experience shortage of qualified personnel and expertise in the area of biomass. These organizations do focus on many other issues and biomass is more often a small component of their activities or programmes. This situation is aggravated by the fact that the institutional linkages between the various actors are weak and in some cases non-existent. There is need to enhance collaboration and exchange of experience between all the actors. The situation if further aggravated by the fact that financing mechanisms are not available for the BET. Many Micro Financial Institutions are not yet convinced of the potentialities of these technologies for the development of the rural populations.

2.5.4 Objectives of Biomass Energy Development Strategy

An ideal biomass energy strategy should ensure that resources are used sustainably without negative social, economic, and environmental consequences. This requires balancing the supply and demand of biomass energy. While the energy sector is responsible for energy supply and demand, a number of other sectors have a niche in biomass energy issues. These include forestry, agriculture, environment, industry, health, population, gender and education. Various other stakeholders are involved in supply and demand aspects of biomass.

The Energy Department has developed a National Energy Policy. The major strategy for implementing the energy policy in end-use sectors is energy efficiency. The biomass (and other renewable) supply sub-sector's objective is for "Government to provide focused support for development, promotion and use of renewable energy resource for both small and large scale applications". The policy provides a list of strategies, which need to be developed further in order to address the needs of the sector. The National Forest Plan emphasizes biomass energy conservation through "Developing a biomass energy strategy, improving uptake of energy efficient technologies and developing appropriate technologies for production, processing, and energy consumption". The National Environment Action Plan also emphasizes energy efficiency, increased production of trees, and increased use of alternative energy sources.

The major objective of this initiative is to synchronise and build on the strategies from different sectors that address biomass energy demand and ensure that stakeholders of the sub-sector play roles based on their comparative advantages in formulating and implementing the biomass energy demand strategy.

The issues to be addressed in this strategy are:

- Institutional Arrangements;
- Human Resource Development;
- Mobilising Financial Resources;
- Dissemination and Awareness;
- Quality Control; and
- Research.

2.5.5 Institutional Arrangements

Biomass energy should not be viewed as an isolated sub-sector but as an integral part of the development process. Uganda's economy is agro-based and biomass plays a key role in a number of agro-processing industries; therefore developments in the biomass energy sub-sector will contribute towards the Plan for Modernisation of Agriculture (PMA). Biomass plays an important role in ensuring food security because it is and will continue to be the major source of energy for cooking for the next decades. In some wood fuel deficit areas, households have shifted from more nutritious foods that take long to cook to less nutritious easy-to-cook foods.

Apart from existing potential, biomass can play a role in power generation for rural based industry (rural electrification) thus contributing towards industrial development.

A revision of the pricing and taxation policies for wood fuels is a condition for the attainment of the policy targets. The level of taxation has to be raised step by step to promote management of the resource base. The primary objective of taxation policy for household energy should be to correct market imperfections that prevent prices on the market to reflect the correct economic cost of fuels. This would convey the correct price signals to the consumer of the cost of his fuel use to society and encourage a switch to the use of improved technologies and other energy sources.

Innovative institutional strategies are required in order to ensure that the energy needs of end use sectors that rely on biomass energy are met. Important institutional options include but not limited to:

- Careful review of the existing institutional framework to identify opportunities for rationalization and improve efficiency. This would include a functional analysis of agencies involved in the biomass energy sub-sector. In addition an analysis of the strengths and weaknesses of the existing institutional framework would help identify areas that need strengthening or improvement.
- Giving preference to simple policy instruments that yield substantial results at low cost.
- Formulating simple regulatory and fiscal measures that are commensurate with local enforcement and monitoring capacity. These measures should be based on

realistic and technically proven strategies with stakeholder participation. For example licensing charcoal producers and fuelwood dealers at village, parish or sub-county levels would be best effected when local authorities have been involved in preparation of environment action plans which incorporate energy at local level.
- Using research results to guide decision-making process.
- Incorporating energy planning at lower levels, mainly at district and sub-county levels.
- Undertaking regular and periodic reviews of past biomass energy policies, projects and initiatives to ensure that lessons learnt are incorporated in current and future activities.
- Ensuring that government departments focus on their central functions of regulations, evaluation, and monitoring.
- Establishing appropriate pricing schemes for wood fuels to allow full recovery of cost for energy crops thus creating a favourable environment for investment in commercial energy plantations.
- Strengthening institutional database, proactive advocacy, and reinforcing effective national coordination.
- Encouraging the establishment of energy service companies (ESCo) with special interest in promotion, testing, manufacture, and marketing of energy efficient technologies and practices.
- Encouraging the development of professional energy-related associations.
- Encourage inclusion of biomass issues in rural development projects.

2.5.6 Human Resource Development

Successful energy programmes in Sub-Saharan Africa are those in which local initiatives played a dominant role in the project conceptualization through to implementation. Meaningful development of the biomass energy sub-sector will require mobilization, strengthening and effective organization of human resources in the country. Limited local participation has retarded the growth of local skills making Uganda more dependent on external expertise. In the short term, optimum use of existing skills would yield the highest benefits at the lowest cost. It is therefore necessary to establish the existing human resource capacity in the country. Over the years, there has been great dependence on external expertise in the energy sector. Appropriate long and short-term training should be made available to ensure that those employed in the biomass energy demand sub-sector can effectively participate in various aspects of biomass energy production, distribution, and use. Among end-users, there is limited knowledge of biomass energy efficiency opportunities and availability of new technologies. Little is known about the capacity to undertake energy efficiency analysis and the simplicity with which energy savings can be used to increase production and profitability in small and medium enterprises.

Some tertiary institutions such as the Faculty of Forestry and Nature Conservation at Makerere University and Nyabyeya Forestry College have incorporated biomass energy in the forestry training curricula. This is the beginning of a process that will supply trained cadres for the sub-sector. In order to accelerate technology adoption rates, it is imperative to include biomass energy conservation in other tertiary institutions and at lower education levels. Some aspects of forestry and environment conservation are now part of the syllabus in primary and secondary schools in Uganda. It is envisaged that the younger generation will implement what they learnt in school. This could also be done for biomass energy conservation.

A number of institutions such as Nyabyeya Forestry College and Makerere University Faculty of Technology are planning to establish "Biomass Energy Centres" in different parts of the country. In addition 12 Agricultural Research and Development Centres (ARDC) (former District Farm Institutes) currently under National Agricultural Research Organization management and Agricultural Development Centres (ADC) under Local Government management can be used as technology uptake pathways for biomass energy technologies. These efforts need to be coordinated to avoid duplication.

A few formal and informal entrepreneurs have invested in production of biomass energy technologies especially production of improved cook stoves. They often have limited technical and business management skills. As a result, these businesses have not registered the success originally expected. Different small projects plan to provide training in both technical and business management skills for improved charcoal stove producers. Other small and medium scale entrepreneurs in the sub-sector need training as well.

In order to create a critical mass of personnel to implement the biomass energy strategy it is imperative to:

- Conduct a human resource survey among major actors and agencies to establish existing human resource capacity. This will help establish the gaps and thus plan for relevant training programmes. In addition, a training needs assessment should be conducted among stakeholder.
- Develop required human resource capacity to implement the National Biomass Energy Demand Strategy by:
  - Providing formal and on-job training for all levels of personnel in biomass energy projects. Training courses should be based on identified local needs of the target groups.
  - Training extension workers in relevant biomass energy technologies. Under the NAADS system extension staff hired by the district authorities will be the major link to farmers. Such training would be conducted if the farmers have identified biomass energy conservation technologies as necessary input to their agricultural development activities.
  - Training staff and managers of small and medium enterprises in technical and business management after training needs assessment.

- Establish a network of trained biomass energy auditors who will be skilled in identifying and implementing profitable biomass energy efficiency initiative.
- Integrate biomass energy conservation in the school curricula at primary and secondary level.
- Co-ordinate biomass energy centre activities and establish demonstrations at ARDC and ADC.

2.5.7 Mobilizing Financial Resources

The level of dependence on external sources to finance energy development in Uganda is so prevalent that little thought is given to mobilizing local financial resources. Uganda has borrowed massively to finance the power sub-sector. On the other hand, the biomass sub-sector, which is an important source of livelihood for Ugandans mainly benefits from small grants. Mobilizing local financial resources is a pre-requisite for sustainable energy development in the country. A few private sector biomass energy initiatives have been implemented using locally generated resources however, experiences on the success of these initiatives is limited. Biomass energy supply is totally financed by local capital however it is characterized by under-valuation of the resource. Some financial institutions administer a number of special loan programmes, which are dedicated to the development of small and medium enterprises. Private sector agencies involved in biomass energy should take advantage of these loans.

Some biomass energy technologies such as biogas systems and institutional stoves; and, technologies for harnessing alternative fuels have high investment costs, which discourage end-users from acquiring these technologies. The first biogas digesters introduced in Uganda were made of concrete and/or bricks, which most farmers could not afford. Currently Integrated Rural Development Initiatives is disseminating a tubular biogas digester, which is cheaper. However, farmers still need financial assistance in order to purchase the biogas system. High investment cost may also affect the adoption of liquefied petroleum gas despite the fact that the industry has introduced cheap 5 kg cylinders with single burners.

Effective financial resources mobilization can be realized by:

- Developing mechanisms for mobilizing local capital to finance biomass energy projects. An Energy Development Fund could be established with contribution from a given percentage of tax revenue from all energy suppliers. Percentages could depend on volume of business and levels of pollution from the fuel.
- Encouraging greater involvement of local banks in biomass energy investments similar to the arrangement for acquisition of solar home systems. Small and medium enterprises should take advantage of loans provided by banking institutions.
- Include smart subsidies for biomass energy initiatives as part of the already established Rural Electrification Fund.

- Rationalizing the collection of revenues, fees and taxes related to wood production, transformation, transport, and marketing at local levels. Those funds should be utilized to ensure maximum benefits are realized at local government level while promoting the commercial woody biomass sector to operate on a sustainable basis.
- Developing appropriate financing packages for small and medium enterprises in biomass energy projects.
- Promoting technology acquisition especially for alternative fuels through hire purchase system. This would be applicable for charcoal production technologies, institutional stoves, biogas and liquefied petroleum gas. In addition, revolving fund systems to enable farmers acquire tubular biogas digesters could be established. However, an assessment of these end-user financing systems is required before wider use.

2.5.8 Dissemination and Awareness

A number of agencies are actively involved in awareness and dissemination activities particularly for improved cook-stoves and tree planting. For most biomass energy consumers, reducing energy costs at end-use has not traditionally been a principal concern. There is need to make information more readily available to enable biomass energy users incorporate energy efficiency in their daily practices. While biomass energy technology dissemination efforts have been going on by different actors over the years, some of these agencies are bound to have registered successful dissemination. It is imperative to learn from experiences of different actors. It is also necessary to consolidate dissemination efforts and channel activities to where there is great need. The different media (press, radio, and television) and the professional associations concerned with Environmental and energy issues will have a crucial role to play in preparing and disseminating the information.

Innovative dissemination and awareness approaches will include:

- Designing a national awareness campaign to demystify biomass energy technology (BET) and ensure actors are aware of key components of the biomass energy demand strategy. The awareness campaign would among other things provide information on biomass energy saving methods including different technology options, major actors and sources of information. The different media and the journalists associations will be trained to disseminate the right messages.
- Creating a database with information on technologies available and their performance parameter, institutions, and their roles in the National Biomass Energy Demand Strategy, past, present, and future projects, and any other information considered necessary.
- Documenting and publishing reviews of technology dissemination activities so that other actors may learn from success and failures of past projects.

- Consolidating dissemination activities implemented by different actors to prevent duplication of efforts and concentration of activities in a given region of the country. This will help identify gaps in current dissemination approaches. Combined with data on biomass growth, demand, and supply, the dissemination approach would include identification of areas most suitable for implementation of biomass energy programmes.

2.5.9 Quality Control

Poor quality of some Biomass Energy Technologies is a barrier to large-scale dissemination. This is particularly prevalent in improved charcoal stoves but may also affect other biomass energy technologies and so there is a need to stop the trend before it spreads too far.

It is proposed that:

- A National Energy Reference Centre be developed at Makerere University where some limited testing facilities for improved stoves have been established.
- A regular testing programme be instituted to ensure that acceptable qualities of goods and services are maintained.
- Quality guidelines and standards for production of different biomass energy technologies should be developed and technology producers provided with the information.
- Technology producers be encouraged to use trademarks on all their products.

2.5.10 Research

There has been limited support to research in biomass energy technologies. Research activities have mainly concentrated on charcoal production and improved cook-stoves. Uganda mainly depends on research conducted in other countries. Continued reliance on technology development done in other countries is expected to persist for many more years but effort should be made to reduce it. It is however imperative that technologies are adapted to suit local needs. Research should therefore focus on:

- Collecting and processing relevant data for the implementation of the biomass energy strategy. Data on biomass availability is an important input to planning at lower levels.
- Incorporating environmental costing in analysis of different energy options to ensure that the realistic cost of biomass energy is applied.
- Developing national energy efficiency performance data, management regimes, and relevant technical specifications for different biomass technologies.

- Developing or adapting technologies for biomass uses where improved technologies are not yet available in the country.
- Exploring the possibility of using biomass for electricity generation and also as a source of liquid fuel that can be used to blend imported oil-based fuels.
- Promoting energy policy analysis research to assess the impact of different energy mix strategies.

2.6 Energy Contributions by Source

Energy consumption in many developing countries is not clearly documented as people tend to use whatever they can get readily and cheaply and therefore both cost and the source become the most important consideration. In East Africa, the following are the common energy sources:

Firewood: This is a common source of energy used by about 90 % of the rural households and about 10 % of urban households. About 80 % of these people obtain their firewood free while others either regularly purchase it or supplement their free collection by purchasing some. Firewood is mainly used for cooking and space heating.

Charcoal: Of those who use charcoal, 80 % of them are urban households while less than 20 % are rural households. The average per capita charcoal consumption in the region is about 150 kg, giving charcoal a significant trade volume, which, in financial terms, could be as high as 50 % of the cost of oil imports.

Wood waste: Use of wood waste is gradually declining with less than 3 % using it in the 1990s compared to the reported over 5 % in the 1980s. This is due to the declining number of special stoves that use wood waste such as sawdust.

Farm residues: These are used mainly in the rural areas and are generally seasonal depending on the periods of harvest when they are available in large quantities. However their continued use will compromise opportunities for improving soil fertility.

Biogas: The contribution of biogas as an energy source both in rural and urban areas is negligible but the potential exists in some parts of the region where keeping animals is a traditional pride. This practice is however rapidly spreading to other areas where such traditions did not exist and there are already a number of biogas plants operated by some farmers and institutions. The potential for biogas will therefore continue to increase.

Kerosene: About 95 % of the rural households and about 90 % of the urban households use kerosene principally for lighting. It is estimated that the per capita kerosene consumption varies from about 40 L in the rural areas to about 90 L in urban areas. Quite a large number of urban households use kerosene for both lighting and cooking and this is one of the reasons for its high consumption in the towns.

Liquefied Petroleum Gas (LPG): This is usually used as a stand-by or emergency energy source and therefore very little is consumed. In urban households it is used as support for the more expensive electricity or when kerosene cannot be immediately obtained while in rural households it is used along with firewood. Using LPG has also been limited by the fact that distributors have special components that cannot be interchanged, for example, Total Oil Company uses LPG cylinder with a regulator that cannot be used by those who have regulators from other distributors. The situation is however changing with the recent introduction of universal regulators that can fit cylinders from different sources and with the recently discovered oil deposits in the region, energy mix pattern will definitely change especially in the electricity generation sector.

Electricity: Electricity is the most modern and convenient energy form. It is also considered to be clean and versatile in its applications including the running of household appliances such as radios, TVs, refrigerators, etc. It is however, expensive for the majority of households. Even in the urban areas where it is readily available, still less than 50 % of the households use it regularly. The situation is far worse in the rural areas where it is not accessible in many areas. There are doubts that even if it were easily accessible, many people would not use it. The scenario in the towns is a clear evidence of this assertion that electricity may be accessible but still very few households would be connected. Almost all the electricity in the region comes from government controlled facilities with about 60 % generated by large hydro power stations while others are from geothermal, oil or gas-fired generators. Renewable sources of electricity such as wind, solar and cogeneration have not made any impact in the energy scene.

It is clear that there is a whole range of energy options but unfortunately some of these have not been adequately considered in official energy concerns even though they have been harnessed in East Africa for different purposes and at different levels in terms of applied technology. It is important, for long term planning, to also assess how much energy is available in the region for further development. This information enables energy planners and those who wish to invest in the energy sector to make decisions on the type of energy resource that would be worthy of consideration with respect to availability, consumption trends, and quantity. We have noted that the end-user requires energy mainly in the form of heat, light, or electricity for operating household appliances, equipment and machinery. In addition to national grid power supply, there is widespread use of rechargeable lead acid batteries and dry cells particularly for emergency lighting and home entertainment. Some of these are relatively more expensive but are used even by those considered to be poor. The reasons for this will be addressed later.

Petroleum Products: These include various grades of fuels such as diesel and petrol (gasoline) used mainly in the transport sector and to a small extent in industrial operations Other related products like kerosene and LPG have specific applications as heat sources mainly for cooking and are therefore given attention in above separate sections. Transport has been a major consumer of petrol and diesel and this is where the governments have been spending the largest part of their foreign earnings. It is hoped that the discovery of oil in Uganda and Kenya will change the situation.

2.7 Energy Planning and Provision Challenges

Since the three East African countries got their independence from the British colonial rulers in the early part of the 1960s, provision of energy has been one of the most sensitive and sometimes thorny issues in the region. The three governments have always tended to put too much emphasis on oil and electricity, both of which are playing a very important role in the transport and industrial sectors. However, at the household level, they have not made any significant impact since most households rely on biomass energy sources (mainly wood and charcoal). The few households, which are connected to the national grid, use electricity for lighting and operating household appliances but usually not for cooking. Very few people would use it for cooking. Most domestic needs for electricity do not require high voltage electricity. The large hydro power stations, which have been developed in the region, produce high voltage electricity and therefore target industrial applications. The high voltage is also good for long distance transmission due to power loses in the process. These characteristics make centralized grid electricity too expensive for household end-users, who generally are only interested in lighting and running of household appliances.

A cheap decentralized generation facility that would target rural lighting and also stimulate small-scale rural enterprises that do not require high voltage would be more appropriate for rural conditions. The governments should not spend billions of dollars to extend national grid electricity lines to scattered rural settlements where the greatest need is for lights and home entertainments. It is therefore surprising that the governments have ignored these options. Perhaps this is why the governments found it necessary to impose state-managed monopoly on production and distribution of the two major commercial sources of energy—electricity and oil. What reason would a state give for ignoring the plight of its poor citizens? This and many more questions may be asked but the fact remains that the state will always be interested in the ventures that have the capacity to either pay large taxes or to directly generate huge revenues and there are good reasons for this.

Another important aspect to consider is that despite the well-known fact that state businesses are generally mismanaged, leaders still found it attractive to allow the state to manage certain businesses in total disregard to the large losses incurred. In recent years, the states of East Africa privatised a number of state institutions that were essentially doing business rather than providing suitable environment for private enterprises. The energy sector incidentally was not privatised until the so-called development partners imposed very tough conditions. It appeared that some of these utility corporations were occasionally used as sources of funds for politically motivated projects and also for quick accumulation of personal wealth. It is has become apparent in Kenya that the state monopoly, Kenya Power and Lighting Company, provided funds for questionable purposes, which were deliberately concealed as general losses made by the Company. Obviously the taxpayers' money would be used to offset such 'losses' and the accounting officer would be fully backed by the political leadership for the "good work" done. However, the problems of the electricity sub-sector have been more profound than just official stealing of funds.

The major problems are associated with the overall management arrangement, regulatory framework, and their relationships with the policy maker. In Tanzania, for example, TANESCO was the sole public utility responsible for electricity generation, transmission, and distribution and was, at the same time, the policy maker and the regulator of electricity industry. This situation was quite similar to KPLC in Kenya and UEB in Uganda. But this was not the only problem; there was widespread dissatisfaction with operational performance and also the government's inability to finance further development of the sub-sector. It became necessary to change this trend by introducing reforms that would not only revitalize investment in the sub-sector but also increase electricity production, transmission, distribution, and sales. Thus reforms in the power sector in all the three states were introduced, first, to correct anomaly in the institutional arrangements and secondly to attract private investment and increase efficiency in the electricity sub-sector. The costs of reforms, understandably, were to be met by the same development partners who previously supported the governments that mismanaged the sub-sector.

To implement the reforms, the governments were expected to enact some laws that would pave way for the creation of other bodies to take up some of the responsibilities of the sole state monopoly companies and also allow the involvement of independent power producers in the generation of electricity. Some glaring questions that should be asked are: Will these moves increase accessibility to electricity in the rural areas? What planning considerations will be given to presently used non-commercial energy sources on which rural communities heavily depend? One of the strategic objectives of the energy sector is to ensure reliable, accessible, and affordable energy and therefore diversification of energy sources becomes important so as to ensure that natural disasters like drought have very little effect on overall production and distribution of electricity. Diversification of sources and attraction of private sector into electricity generation is expected to encourage the development and use of renewable energies such as solar and wind but the governments will have to make deliberate efforts to provide enabling environment for these to happen.

Then there is the question of energy conservation for purposes of protecting the environment and resources. Economically recoverable oil has not been found in East Africa and so the region depends on oil imports mainly from the Middle East and the governments will continue to spend their limited foreign earnings on such importation. There is need to control this not just through pricing but also through efficient use of oil-based fuels and use of alternative sources. The transport sector is therefore an area that requires special attention with a view to reducing oil consumption. The implication of this is that roads and traffic rules must be designed to reduce fuel wastage in addition to diversifying modes of public transport and making them more convenient, comfortable, and attractive in economic terms. These are far reaching challenges that mere reforms that are restricted to electricity generation and distribution cannot address.

Furthermore, the reforms are not addressing the concerns of the majority of the population who simply require heat energy for cooking and a little kerosene for lighting and who have independently managed their own source of heat for many years. Kerosene is used by an increasingly large number of rural people because it can be bought in small quantities and the user can regulate its use. Access to electricity should also be arranged in such a way that the user pays for what is consumed only and not for all sorts of gadgets including meters which belong to the utility company. The level and payment of electricity connection fee should also be user friendly, for example, 50 % of this could be distributed in the electricity bill for a period of one or two years. Introduction of prepaid meters where the consumer's supply is based on ability to recharge the meter could also encourage people to apply for grid connection. This method was introduced by TANESCO in Tanzania and there were signs of increased demand even among the low-income groups.

Energy provision challenges in East Africa can be seen in the following contexts:

- **Legislative aspects**, **which are very unfriendly to and exploitative of the consumer**: For example the imposition of the mandatory minimum standing charge that the user must pay even if there is no consumption of electricity during that period. This has been a source of many complaints and has discouraged many prospective clients from getting connected especially in Kenya. The second example is the requirement that in order to be connected, the applicant must pay the cost of all the materials needed for the extension of power to the consumer's premises.
- **Legislative aspects, which discourage investors from participating in the electricity sub-sector**: Although this is expected to be corrected through proposed reforms, it is unlikely that the new rules will allow independent electricity transmission and distribution companies to operate. Reforms that are restricted to the generation and sale to a single utility monopoly will not have the impulse that is required to liberalise the electricity sub-sector.
- **The level of poverty of the people**: The level of poverty is relatively high in the region especially in Kenya where more than 50 % of the population lives below poverty line. In both Uganda and Tanzania about 36 % of the total population

live below poverty level. This is a major drawback in the effort to improve electricity accessibility in the rural areas.

- **The land ownership laws**: That encourage the establishment of scattered settlements or establishment of 'homes'. This has always made it too expensive to implement electricity line extensions to the consumers so that even those who can afford to pay for it are normally reluctant to get connected.
- **Electricity pricing policy**: There are many factors that are considered in pricing electricity and practically all the costs are passed on to the consumer. Most of these costs are based on long-run marginal costs including fixed operational and maintenance costs and variable consumables such as fuel margins and overhead costs. In addition to these there are taxes and levies, which may be imposed to carter for further developments such as rural electrification. The disappointing fact is that although consumers pay for all these expenses and levies, the money is hardly used for the intended purposes. The actual tariffs, however, vary from country to country. For example, Tanzania implemented tariff reductions especially for industrial customers but this only brought them down to the level of the Kenyan tariffs. In Uganda the Tariffs are much lower and in this regard many new industrial establishments in the region prefer to set up their businesses in Uganda.
- **Over reliance on hydro as the main source of electricity**: This has forced utility companies to occasionally ration electricity due to low levels of water in the reservoirs. Kenya has been the most affected by this because its five major hydro stations are on one river and, worse still, one dam is the main reservoir for all the five stations.
- **Frequent electricity interruptions**: Servicing and maintaining electricity grid network continue to be a serious problem for the utility companies. These interruptions often cause power surges that damage electrical appliances and it is estimated that consumers lose millions of their hard earned money through such power surges. In Kenya, an average of about 11,000 unexpected interruptions of electricity supply is reported every month but the actual number of cases is higher than this since many cases are not reported. Losses are also incurred through illegal connections are estimated to cost KPLC over 15,000 US dollars per year.
- Finally, there are the perennial management problems of general inefficiency including rampant misappropriation of funds.

Detailed information on these challenges is available in many publications [9, 16, 21, 23, 25, 27, 28, 34, 36].

This last context appears to have been the main reason why international development partners applied pressure on governments to introduce reforms into the electricity sub-sector. The desire was to dismantle the electricity supply structure, which was dominated by vertically integrated state-owned electricity utilities, and open the sub-sector up for independent investors most of whom would come from the more developed countries. If the reasons were more than these then obviously all energy resources of significant values would have been considered and more emphasis would have been put on rural electrification. But the reforms do not address these directly although they may have some implications on the development of other energy sources and also on rural electrification. It has all along been evidently clear that the monopolistic management structure was a significant contributor to the under-performance of the region's power utilities that were characterized by unreliability of supply, low capacity production, deficiency in maintenance, high transmission and distribution losses, high cost of electricity, and inability to mobilize sufficient investment capital. These were bad enough by any standards but the question is: Would the proposed reforms address all the above problems? And for how long and to what extent are the poor developing countries going to depend on oil, which they have to import at increasingly heavy sacrifices? It must be noted that more than 75 % of the world population is in the developing countries and any increased demand and use of oil in these countries will have dire consequences on the environment by accelerating climate change and global warming processes to unprecedented levels. Increased demand will also raise the price of oil and hence greater sacrifice for the developing countries to import oil. In addition, world oil reserve will rapidly decline if substantial new reserves are not discovered. Care therefore must be taken in handling the use of oil and other fossil-based fuels. The energy reforms in East Africa appear to have downplayed future implication of increased oil consumption on the economies of the three countries, and also on the environment. As world oil reserves decline, it would not be surprising if the next energy reforms imposed limits on oil consumption.

While making efforts to address the challenges, due regard must be given to the protection of the environment, the expansion of energy infrastructure, firm security of supply, diversification of sources, and accessibility to all sectors of the population with special attention to the rural population. All these should be considered as aspects of energy provision challenges. In addition to these, the people must be made to understand the need for energy conservation.

2.8 Energy Reforms: The Immediate Challenge

Compared to other parts of the world, East African power sector reforms have been slow and to a large extent, limited to divestiture of the traditional state-owned power corporations and entry of independent power producers. The aim was to meet shortfalls in electricity generation and also improve efficiency of supply. These are issues that are of great interest to the manufacturing and general industrial activities but may mean almost nothing to the more than 80 % of the population who have no access to electricity. One may argue that although these people have no access to electricity, they are also beneficiaries of industrial output and other electricity-supported products. However, the global power supply concerns are about people and, naturally, large scale availability of power to the people also creates the desire to set up new industries. The Power sector reforms that have been carried out in East Africa basically targeted and indeed affected the electricity

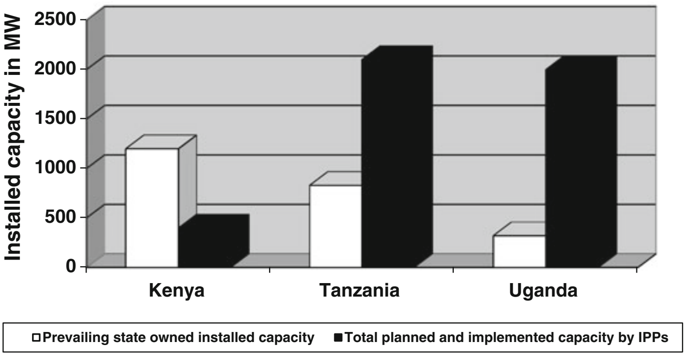


Fig. 2.17 National capacities compared with those of independent power producers [29]

sub-sector. The major turning point in this process was the amendment of electricity Acts in the second half of the 1990s by the three states of East Africa [18]. It was these amendments that purportedly created the enabling environment for the operations of independent power producers and the unbundling of the state-owned monopoly companies. The individual national parliaments in 1997 and 1999 passed these amendments in Kenya and Uganda respectively.

In Tanzania, the process started in 1992 when the government changed its policy to allow the participation of private sector in electricity generation. In 1999, a new electricity policy was introduced and in 2001 an Act of Parliament established Electricity and Water Utilities Regulatory Authority (EWURA). The impacts of these policy changes have been measured in terms of the number and capacity of independent power producers (IPPs) in relation to the traditional suppliers. Indications are that Tanzania and Uganda will give the independent power producers the major share of electricity generation under more favourable environment than Kenya and therefore fewer IPPs are showing interest in operating in Kenya.

It is clear from Fig. 2.17, that both Tanzania and Uganda have attracted a lot of interest from independent power producers. In Uganda there are IPPs interested in hydro generation of electricity while in Kenya there are some who are already involved in using geothermal as their source of electricity. Most of the independent generators, however, are engaged in fossil-based generation methods, which obviously will increase national expenditure on oil imports. In Uganda and Tanzania, the high hydropower potential and governments' policy on their development and management appear to be the main attraction for IPPs. The presence of coal and natural gas in Tanzania may also appeal to some IPPs but, in general, the institutional arrangement for managing the energy sector is an important factor that most private investors would want to consider. In terms of legislation and the restructuring of institutional arrangements in the management of the energy sector, the previously single control by KPLC in Kenya, TANESCO in Tanzania and UEB in Uganda have been removed by the creations of new bodies to deal with generation and regulatory matters. A brief look at the amendments of the electricity

Acts indicates remarkable differences in the emphasis on various issues such as rural electrification, tariff changes and possible levies. For example, the Kenyan Act addresses the issue of access only to a limited extent and trivially mentions rural electrification process while giving the minister concerned powers to introduce levies and decide where and how rural electrification is to be conducted. The minister may establish rural electrification fund, but there is no firm guidelines on this. The Ugandan Act, on the other hand, puts more emphasis on electricity access in the rural areas and gives the Minister responsible the authority to develop a sustainable and coordinated Rural Electrification Plan and Strategy, establish Rural Electrification Fund and determine the criteria and appropriate level of subsidy. Furthermore, the Minister is expected to keep and maintain National Rural Electrification Data Base to assist in monitoring the progress. It is clear that while Uganda is showing a lot of concern for rural electrification, Kenya does not seem to be interested and does not even mention the possibility of subsidy. In Tanzania, the Rural Energy Master Plan includes renewable energies and proposals to set up Rural Energy Agency and Rural Energy Fund. These are expected to spur rural energy development but there are doubts that, with privatization of TANESCO, the distribution companies will have any incentive to carry out rural electrification. These reforms have been in place long enough to determine their impacts on electrification status in the region in order to assess the real challenge in this respect. In Tanzania, the reform process started in the early 1990s when the country was in transition from socialist economic policy to free market economy. Its case is therefore slightly different from that of Kenya and Uganda, and may not provide the real impact of reforms that were proposed by the World Bank. Examples are therefore taken from Kenya and Uganda.

2.8.1 Effects of Electricity Reforms in Kenya

It is true, to some extent, that since the reforms were initiated the performance of the state corporations that managed the electricity sub-sector has significantly improved. Some of them have cleared their past huge deficits and are beginning to make profit. For the case of TANESCO, this improvement could be explained by the fact that professional management consultants were hired to run it, and therefore had to work hard to prove their competence. For both Kenya and Uganda, the improvements could be attributed to the governments' introduction of tough measures against inefficient Chief Executives of the companies.

The Kenyan case is a clear case where a new party came to power and took drastic and stringent actions against Chief Executives who knowingly misappropriated public funds. This is a pointer to the fact that gains could be made and management improved without the introduction of the reforms. This is not to say that the reforms were not necessary. The reforms covered a wider spectrum of issues than just profitability of these companies. The global concern is to see that the more than two billion people who have no access to electricity are connected.

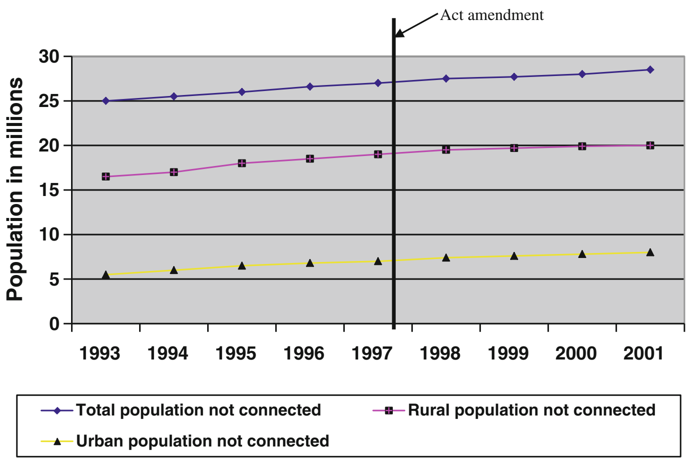


Fig. 2.18 Population without electricity in Kenya [29]

One would therefore expect that since the introduction of electricity reforms in East Africa, there has been a significant change in the rate of electrification levels. This has not been the case in Kenya. It looks like despite the reforms, business has gone on as usual. Figure 2.18 shows this very clearly that the situation has not changed from what it was before the reform-motivated electricity Act amendment. Of course, instant changes should not be expected but some signs should begin to appear three to four years later.

The trend of electrification levels for all categories of people continued without any response to the policy changes. This reinforces the view that the reforms have essentially emphasized the development of IPPs and improving financial performance of state-owned utilities at the expense of rural electrification. In real terms the number of people without electricity continued to increase in both rural and urban areas. It is therefore clear that the new policies do not comprehensively address rural electrification strategies and there are no guidelines on how it should be implemented. In the long run, there may be tangible sectoral benefits of these reforms but this may not trickle down to the majority of the citizens unless reforms are accompanied by comprehensive measures to reduce poverty in the rural areas.

Another measure that is used to determine the extent to which the reforms accelerate access to electricity are electrification rates, which refer to the number of new domestic connections in a specified year compared to the number in the previous year. These rates have remained very low in Kenya in both the periods before and after the policy turning points, indicating that there has not been any impact of the reforms. In fact, in certain cases, the figures were more impressive prior to the amendment of the Electricity Act. It should however be noted that there are other factors that affect the electrification rates such as the fluctuating cost per connection and increased population. It seems that the arrangement where KPLC funds Rural Electrification while at the same time free to use the same funds to offset any operational losses has made it almost impossible for rural electrification programme to succeed. The logical conclusion is that the management of Rural Electrification Programme in Kenya has been ineffective due to the government's lack of interest in its progress. This is confirmed by the fact that the proposal to establish rural electrification agency came at the end of the reform agenda and appeared to have been an afterthought given that it was not even provided for in the Electricity Act. Kenya Power and Lighting Company will continue to play a key role in rural electrification process and given that it was only recently salvaged from near collapse, it is likely to pay more attention to the improvement of its operations rather than to rural electrification. To maintain some sort of growth, it is likely that KPLC will continue to concentrate its distribution activities in urban areas where the extension of grid power line is cost effective due to high concentration of consumers in one area. Consequently the future of rural electrification in Kenya will continue to be very bleak.

2.8.2 *Effects of Electricity Reforms in Uganda*

Access to electricity in East Africa is lowest in Uganda with less than 5 % of the total population electrified. As in the Kenyan case, consideration is given to the population not connected in urban and rural areas and also the overall situation in the country. Figure 2.19 gives details of these from 1996 to 2002 [19].

There has been a general trend of marginal increases in accessibility to electricity since 1996 within the population categories examined and this trend continued even after the amendment of Electricity Act in November 1999. Like Kenya, the changes in electricity management policy as a result of the amendment of the Act have not

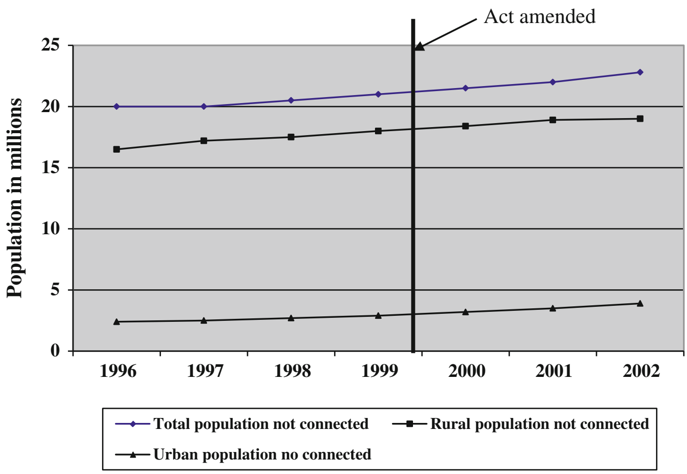


Fig. 2.19 Population without electricity in Uganda [29]

made any difference in the situation of the majority of people living in the rural areas. Although there is a plan to implement the Energy for Rural Transformation Project in order to increase rural electrification levels, it is unlikely that this will significantly benefit the rural communities. This doubt arises from the fact that the target set for this project is too low at 10 % by the year 2012 indicating lack of commitment and seriousness in addressing rural electrification.

Evidence from other African countries shows that for the same period of time it is possible to achieve almost twice as much as this target. Population growth rate, high tariffs, rigid payment modes and the high poverty level will reduce the quoted target to a mere business as usual status and, given the present trend of household electrification rates, even this modest target will not be realized. It is important to note that rural electrification rates cannot be expected to significantly increase without addressing the socio-economic circumstances of the people. In Uganda, the reforms are at an advanced stage but it appears they were undertaken primarily to implement the privatization of the government controlled utility companies. Very little has been done in the area of rural electrification even though there is apparent incentive given by the new regulatory and policy frameworks. The arrangement for rural electrification that has been put in place is basically similar to what has existed before the reforms. It is only formulated in a slightly different style while the government control and involvement is still firmly in place. For example, Rural Electrification Board is headed by the Permanent Secretary in the Ministry responsible for energy and it is known that this arrangement limits the autonomy of the Board and mixes up policy, financial and implantation matters to the extent that there is no proper monitoring of the progress. This was the main cause of the failure of Kenya's rural electrification policy and Uganda is unlikely to succeed with the same approach despite the good statements of intention.

The two examples from Kenya and Uganda are indicative of the major challenges in the electricity sub-sector in East Africa and confirm that, despite the purported changes to improve the electrification levels, the so-called common citizens of this region will not benefit from these efforts. The truth is that the restructuring of the electricity sub-sector is deliberately designed to improve the financial performance of state-owned corporations, obtain addition revenue from IPPs, and increase electricity security for the industrial and manufacturing sectors. To achieve some level of success in rural electrification, the governments must specifically encourage generation of power in the rural areas using resources that are available in those areas particularly small hydro, co-generation, biomass, solar, and wind energies while at the same time seriously addressing rural poverty. Without these, rural electrification will remain an unfulfilled dream for many years, if not forever. At present, there does not seem to be any seriousness on the part of the governments to tackle the issue in an organized manner, as there are no proper records regarding rural electrification status. Even data on rural energy resources and their potentials are not adequate and the little available are not accurate enough to assist potential investors. Official energy targets are given as conditions for issuance of licenses but are never followed up thereafter.

In addition to the electricity issues, there are also challenges in the oil sub-sector to deal with. The region has no recoverable oil at present and yet there is a growing demand for kerosene in the rural areas particularly for lighting. It is fortunate for the governments that presently a large fraction of rural population is not economically empowered to use kerosene freely and therefore this puts a limit to the amount of kerosene used. A situation in which the demand for kerosene can double will put a great deal of strain on the economy of the region and so the governments must prepare alternative energies now and not later. The alternative energy sources that should be considered for the region are solar, biomass, decentralized small hydro and wind. The challenges of these sources lie in their technologies and that is the subject of the next sections.

2.9 The Status of Renewable Energies in East Africa

We have identified energy sources in East Africa and noted that vital and economically crucial energies are fossil-based. Most of other forms of energy including electricity can be obtained by using oil-powered machines. Unfortunately East Africa was not endowed with oil and had to rely on imports that take a large fraction of her foreign earnings. Hydropower and geothermal sources can only produce electricity to light homes and provide power for lighting and operating machines for various applications. They cannot perform all the functions that oil does, particularly in the transport sector. Thus to fully meet energy requirements in East Africa, both oil and other sources of electricity will continue to be used. However, oil remains the most crucial source of energy due to its versatile sectoral applications. It can provide electricity, heat energy, light, and facilitate transportation for which it will continue to play a crucial role for many years to come.

Although oil has been discovered in Uganda and Kenya, it will still be necessary and possible to restrict its use to sectors where there is no alternative. Energy for heat, lighting and home entertainment can be obtained from other local sources and in this regard, top priority should be given to sources that are environmentally friendly and readily available with high possibilities of sustenance. Energy resources that traditionally have been used in East Africa for many years should receive more attention as they have proved that it is possible to sustain their supply. These are biomass, solar, hydro and wind energies. The use of most of these sources has never been officially planned and therefore individuals and small non-governmental organizations with limited specific objectives have haphazardly handled their development and promotion. Thus, lack of coordination and institutional support has inhibited the development of technologies that would efficiently harness these energies.

The new approach will have to deliberately plan and coordinate technological developments for these resources. Through past efforts of non-governmental organization and donor agencies, significant knowledge on options for disseminating Renewable Energies in East Africa has been accumulated but the results of many technological development efforts have been far below expectations. This has been so largely due to the fact that selection, development, and implementation of appropriate technologies were not effectively supported by both legislative and institutional arrangements. It appears the governments did not recognize the complexity of this process and had hoped that, with the accumulation of knowledge and experience, adequate technology transfer would also take place. Unfortunately this did not happen and opportunity that would have pushed the region to a higher level of development was wasted.

In the 1970s when the oil crisis revived global interest in alternative energies, almost all countries that were severely affected started, at nearly the same level, to conduct research in the development of technologies that would harness solar, wind, and biomass energies more efficiently. If Sub-Saharan Africa, in general, paid as much attention to these researches as did the developed countries, the situation would be much different today. It is indeed sad that countries like Kenya, Uganda, and Tanzania, which are located right on the equator where there is abundant sunshine throughout the year are now importing solar energy devices from other parts of the world that receive very little sunshine. It is equally sad that these are the countries whose 90 % of the population still depends on rudimental use of fuel wood without any effort to develop or use modern technology for biomass energy conversion despite the growing demand for it in the region. These are the same countries with landscapes and highlands where there is abundant un-tapped wind energy.

It is known that wind speeds increase with altitude and traditionally people in East Africa do not farm or live on the mountains and high hills. These are areas where wind generators would today be generating power to light the dark and poor villages in the rural areas. Because of the cool climate and fertile farmland around the hills and mountains, the population density is usually high and so many people would benefit from such wind generators. The problem is neither ignorance nor lack of resources. Many of the leaders and local technocrats are fully aware of the opportunities in Renewable Energies since they have interacted very closely (mainly through higher education) with countries like Germany, USA, Denmark, United Kingdom, etc., which are the world leaders in renewable energy technologies especially wind energy. Furthermore, some locally produced wind machines have been operating successfully in East Africa, indicating that there is a reasonable level of awareness in the region.

With regard to availability of investment resources, these technologies are not as capital intensive as some of the developments that have been undertaken by the governments. Biogas digesters, Gasifiers, Wind machines, and Solar cell production plants are not as expensive to establish as, for example, paper, sugar, or steel mills and large hydropower stations, which are found in the region. Renewable energies are the sources of energy on which the majority of the people have relied for centuries and yet they are the resources that the leaders have chosen to neglect. This is not to say that direct government involvement in this process is a prerequisite for their success. In some cases, government's direct participation may even be detrimental to the development of Renewable Energy Technologies but it is very important for the governments to provide visible and attractive incentives through appropriate legislations and institutional framework.

In addition to this, the government, through her extensive service delivery network can be the largest consumer of these technologies by formulating and implementing promotional policy that requires all government institutions like schools, rural housing schemes, dispensaries and hospitals to use appropriate renewable energy sources. The importance of energy in any development process particularly in rural development should be recognized and given the emphasis and support it deserves by establishing institutions that would oversee renewable energy development and application. The existing power utilities in the region have not taken up this responsibility and, given their interests and limitations, it is doubtful whether they can be effective in promoting the development of renewable energy technologies.

In order to diversify energy production in East Africa, it is important to consider the end-use and then choose appropriate source for this. If the end use requires heat only then there is need to choose the source that would efficiently provide that heat and if the end use needs light load electricity then the source should provide just that and the appropriate ones in this case would be solar, small hydro, wind or producer gas-powered generator. It is also important to analyse the number and concentration of the consumers as this will dictate whether the source should be centralized or decentralized. Obviously, for the scattered distribution of rural settlements in East Africa, the most suitable sources for energy supply would be those that are scattered and decentralized just as the human settlements.

This arrangement would not only solve the problem of high transmission cost but would also involve the communities in the ownership and management of the facility. Such community participation are some of the characteristics for sustainability that can only be provided by renewable energies such as small hydro, solar, wind, and modern biomass technologies (biogas, co-generation, and gasification). One major problem so far has been lack of organized data on availability and sites of various renewable energy resources. This makes it necessary for an investor to carry out data collection besides other feasibility studies—a tedious process that most investors are usually reluctant to undertake. It is therefore necessary for the East African countries to undertake an extensive renewable energy resources assessment at both regional and national levels and document them as accurately as possible, giving details of the type, location, quantities and daily, monthly and annual variations of the available energy resources. Additional well-documented information on sites that are economically and technically viable as well as socially acceptable should also be available to enable interested investors to make informed decisions. The issues of quality control and safety requirements would be managed through appropriate legislation and institutional framework specifically established for the development and application of renewable energies.

Previous attempts to promote renewable energy technologies in the regions severely suffered due to poor qualities and wrong unchecked maintenance procedures that seriously undermined consumer confidence. As a result most of them could not stand the test of time. This is an aspect that is threatening the survival of the Kenya Ceramic Jiko, which is considered as a very successful renewable energy device in East Africa. Many manufacturers, taking advantage of the high demand

and working without quality control enforcement, have used sub-standard materials to produce low quality stoves and this is rapidly eroding the consumer confidence. Installation of faulty or incomplete solar energy systems like solar water heaters and photovoltaic panels and the emergence of unscrupulous dealers who knew very little about the technical operation of the systems and consequently gave wrong information to the clients caused a drastic drop in demand for these devices in Kenya.

Biogas plants constructed in the 1980s with a lot of support from donors are no longer in good working conditions because of poor management (irregular feeding, poor and delayed repair works, etc.). Similarly the fuel briquette machines and biogas plants which were promoted in Uganda in the early 1980s are either operating much below the capacity or are not working due to management and maintenance problems. There are many examples in which good renewable energy systems did not succeed because of inadequate technical support and distribution points as well as the absence of quality monitoring and enforcement mechanisms. Obviously rural conditions are also not favourable to traders and some problems arise due to too few dealers who find it too expensive to follow up scattered installations over large distances and consequently such installations once broken down remain so for ever.

Installed wind machines for water pumping and electricity generation have been most affected. For example, in Kenya, the Kijito wind pumps are scattered and technicians have to travel long distances to maintain them and so the maintenance cost incurred by the user is inhibitive and discourages widespread use of the technology. The desire of the manufacturers of Pwani wind pumps to remain in the market forced them to sell their products within manageable distances so that they can serve their customers effectively. At the moment, renewable energy devices particularly wind, solar and some biomass devices are thinly spread out in the expansive East African territory and the number of qualified maintenance staff is too few to carry out cost-effective repairs. The situation becomes even worse when the system is wholly imported so that the user does not have anybody to turn to for assistance. All these factors put a lot of constraints on renewable energy systems and therefore deliberate efforts must be made to effectively address them.

One way to do this is to encourage local production centres for the systems that require initial large investments like wind machines and solar systems as well as the development of local manpower for maintenance and repairs. Manpower development should cut across all sectors of the society from artisans to university graduates with the capacity to continue with research and technical modifications. This will call for the development of suitable training syllabuses at all levels of education and training institutions. The need to set up institutions specifically charged with the responsibility of developing from within, and acquiring from without, renewable energy technologies that are appropriate to the different circumstances of the users is long overdue. It is only through such institutions that some progress can be made and evaluated. The various ministries in charge of energy matters should have, as their main extension responsibility, renewable energy development section that should promote and coordinate research in energy technologies. So far there are a number of institutions responsible for various issues such as monetary studies, cooperative development, meteorology, mass communication, and so on, but there is none for energy studies and development. Yet without energy, no progress would be made in any of those other areas. Admittedly, there are already a number of renewable energy activities going on in research institutions and universities in East Africa, but these are very haphazardly done with almost no participation at the national level. In Kenya, Kenyatta University established the Appropriate Technology Centre to train students up to postgraduate level on various aspects of technologies with renewable energy technologies as the main focus of the programmes. The departments of mechanical and electrical engineering in other public universities are also engaged in research covering renewable energy technologies. University of Nairobi, University of Dar-es-Salaam, and Makerere University are all doing research in various aspects of renewable energy technologies including solar energy materials for PV cell production. However, at the national or regional level, nobody cares what happens to the results of such academic research efforts. It is very necessary to recognize the importance of energy when formulating investment incentives so that both the government and the private sector can work together to not only support but also give research contracts on renewable energies. It should not be left to the individual researcher to decide how and what aspect of energy to study. In spite of national governments' apathy, some local energy specialists have carried out useful studies that can form the basis of future renewable energy development strategies but, again, such information is of no use if there is no planned and focused programme for relevant further development. The first priority therefore is to establish a technical institution in charge of research on renewable energy resources and the development of appropriate technologies for their applications.

At present, national governments are supporting various research organizations that are managed as separate entities with very little, if any, inter-institutional collaboration. This is not the best way to manage research activities in a developing country that is operating under very severe resource constraints. Individual institutions are more expensive to maintain than when they are managed under technical coordination of one national body. In addition to this, isolated institutions operate under restrictive mandates that limit their flexibility to accommodate new research and development areas that frequently emerge in developing countries and, as a result, new institutions are established every time there is need to address an issue which is not covered by the mandates of existing institutions.

The developing countries have and will continue to meet new developments issues to deal with and therefore there is need to reorganize research and development institutions in such a way that they can cover these new areas as they emerge. They can however be clustered into groups of related fields in order to improve internal interaction and sharing of expertise and facilities. For example, the broad groups could be: socio-economic development, science and technology development, governance and policy development, etc. All scientific and technological concerns would then be covered by, say, National Institute for Science and Technology, managed by high calibre scientists and covering research and technology development in issues such as energy, medicine, agriculture, veterinary, materials, etc. Such broad-based centres would be used and, if necessary, contracted to develop specific technologies that would enhance national development. The management of such establishments would have collaborative mechanisms with universities in which there is a vigorous exchange of expertise under sabbatical or secondment arrangements.

This is the only way to efficiently and effectively use limited human resources and research facilities that are required at that high level of operation. This arrangement should ensure that energy research and development finds its right place in the region. Once these suitable institutional frameworks are established, the energy concerns should focus on local energy resources, and use the existing potentials in ethanol production, co-generation, small hydropower, solar, wind, and biomass to develop technologies that would lead to use of cleaner energies in the rural areas. The primary aim should therefore be to gradually reduce the use of raw biomass as the main source of energy in the region by employing a deliberate and well-coordinated effort to gradually and systematically introduce its replacements. In order to succeed in doing this, some attention would have to be directed towards changing energy consumption pattern in the region.

Ethanol production potential should nationally or regionally be developed to address the problems that the region is likely to face due to the imminent oil scarcity in the future. Developments of solar, wind, and small hydropower should principally be geared towards improving rural electrification. In this regard, solar energy applications can be approached from two angles: use of photovoltaic technology to produce electricity, and, use of solar concentrators to heat suitable fluids that can produce steam to run turbines for electricity generation. Technologies for both these approaches are still advancing but the currently known processes can be adapted to the local conditions and used to produce electricity at reasonable efficiency levels. Thus it is worth considering some investment on modest solar cell manufacturing plant in East Africa given the long-term benefits that the region will have and the uncertainty surrounding future supply of other fuels.

In the early 1990s, an analysis was carried out that compared the cost of solar electricity with that of grid power and it was established that the lifetime cost of solar electricity was about 25 % lower that grid electricity. Since then, the price per unit peak power of solar photovoltaic panels has gone down, making power from this source more attractive. Application of other sources of energy should also be diversified, for example, biomass technologies could also concentrate on producer gas, biogas, fuel briquettes, co-generation, ethanol production, and organized and efficient methods of charcoal production.

2.9.1 Renewable Energy Research and Development

While technologies that harness fossil and hydro energies are, on average, well developed world-wide, renewable energy technologies are not well developed in

East Africa. Moreover, the distribution of electricity and oil are such that the rural populations do not have instant or easy access to them. In addition, the purchase and maintenance costs of the technologies that utilize these resources are too expensive for the people. Conversely, light, and heat energies from the relatively readily available biomass resources using cheap and low-level technologies can easily be harnessed.

Practically, all East African countries spend less than 1 % of their GDP on scientific research. Consequently, very little resources, if any, are spent on renewable energy research and development. Most activities related to renewable energy technologies are externally funded and are usually initiated by fresh researchers returning home from overseas training programmes. In many cases, the projects are merely a continuation of research work done abroad and may not have any significant impact on the country's renewable energy development programme. Gradually, these scientists are "de-activated" by widespread internal bureaucracy and inadequate financial support, which force them to turn to other activities. In spite of this, a modest number of researchers in the universities are conducting serious research on renewable energy technologies. The private sector is mainly engaged in commercial production and installation of technologies such as solar water heaters, biogas plants, wind turbines, charcoal, and wood stoves. Governments or parastatal corporations control electricity generation by geothermal, hydro and large oil-fuelled generators. Other agencies for example, NGOs are involved in extension work and rarely in research and development.

At present, most of the activities in renewable energy technologies are of the extension type in which non-governmental and the private sector play the major role. Most of the funds for research and extension work come from external sources. Some research and development projects are conducted at the universities and national research institutions with hardly any collaboration with either the policy makers or funding and extension agencies.

The region's research and development programmes in renewable energy technologies are beset with numerous problems including insufficient manpower, lack of clear objectives, lack of analytical skills and facilities, and poor incentives for researchers. Besides, large corporations involved in energy related activities do not locally conduct or contract research works on the development of renewable energy technologies. This policy has alienated local researchers and stifled the development of local capacity for renewable energies. Most of these problems arise from weak and ambiguous renewable energy policies that most of the countries in East Africa have adopted. In fact, some of the countries operate on the basis of haphazard public political pronouncements.

On average, the region is amply endowed with both biomass and solar resources. Both of these can be suitably used as small scale decentralized sources of energy in the rural areas where, for cost and availability reasons, renewable energy systems may be the only option. However, the exploitation of these resources will depend, to a large extent, on the individual country's ability to create or strengthen institutions for this purpose.

Therefore, the lack of large scale adoption of these technologies should not be viewed as an indication of inappropriate conversion device but as a reflection of the inadequacy of their research and development. Moreover, for the full benefits of these technologies to be realized, it is important that researchers appreciate the user needs and match them closely to the existing technologies. Unfortunately, many research programmes in the region do not address these issues at the initial development stages.

2.10 Impact of Energy Use on the Environment

The Earth is a large energy store and its ability to retain that energy depends on the composition of the atmosphere, which to a large extent, is influenced by factors associated with energy production and consumption. Changes in the concentration of atmospheric substances can create climatic conditions that would reduce the earth's ability to support life. Energy production and consumption produce waste products that are capable of up-setting the desirable concentration of atmospheric substances. Every energy initiative must therefore consider strategies that would protect the atmosphere so that it maintains suitable climatic conditions. In this regard, it is important to assess the level of emission of atmospheric pollutants due to energy use in East Africa. Examples are taken from Kenya since it is the largest energy consumer in the region. This information would assist energy planners to choose appropriate energy development pattern for the region.

For the atmosphere to be dynamic, as indeed it is, to maintain its composition, and also to produce suitable world climates, requires energy. This energy comes from the sun; all the necessary conversions and transfers are accomplished through the interaction of solar radiation and matter. These processes naturally maintain the atmospheric composition at a necessary level for suitable climate.

If the world did not have atmospheric gases, the average temperature of the surface would be about 253 °K (−20 °C) but due to the presence of the atmospheric gases, the average observed surface temperature is about 288 °K (15 °C). The Earth is thus kept warm at a fairly steady average temperature by the greenhouse effect of the atmospheric gases whose composition must not be upset. But our reliance on various types of fuels is continuously increasing and this is affecting the natural balance of the atmospheric composition. In modern world, the production and use of energy determines the rate and level of development. Energy is the fundamental unit for the physical development of the world. It provides vital services for human life, for example, power for transport, mechanical work, cooking, manufacturing, etc. This energy comes from oil, gas, coal, wood, nuclear and primary sources such as solar, wind, and water. All these must be converted to the suitable forms for various kinds of machines or any other type of equipment or application. However, every source has its own economic and environmental costs, benefits and risks. Choices must therefore be made with full knowledge of environmental and economic implications. The current trends of both constantly increasing energy consumption and the environmental risks of energy by-products are disturbing.

One of these risks is the observed indication that there is climate change due to greenhouse effect of gases emitted into the atmosphere. Carbon dioxide is the most significant contributor, alone accounting for about 50 % of the combined effect of all greenhouse gases at the present time. The alarming fact is that currently there is no effective technology for removal of carbon dioxide emissions from combustion of fossils fuels. Recent estimates indicate that the accumulation of carbon dioxide and other trace gases in the atmosphere would lead to an increase of the mean global surface temperature of between 1.5 and 4.5 °C by the year 2030 if nothing is done to stop the trend. The effect of this global warming would be disastrous.

Let us now confine the discussion to the emission of CO_2 into the atmosphere. As has been mentioned, carbon dioxide is one of the most effective greenhouse gases in the atmosphere and its increased concentration will adversely affect the climate. It is generally accepted that carbon dioxide concentration has constantly increased at the rate of about 4 % per day during most part of this century. It is estimated that at this rate, about 5×10^{10} kg of carbon per year is added to the atmosphere. Deforestation and changes in land use are other sources of the increasing atmospheric carbon dioxide besides its release from the burning of fossil fuels. Although oceans and forests act as partial sinks to the emitted CO_2, it is clear that continued use of fossil fuels will lead to an increase in the atmospheric CO_2 concentration. Climate observations and studies with climate models suggest that the doubling of CO_2 concentration would give an increase in the global average Earth surface temperature of 1.5 to 3°C, all other factors being constant.

2.10.1 Energy Contribution to CO_2 Emission in Kenya

Most of the reports and predictions of a future climate change due to increased atmospheric greenhouse gases have been based on a combination of guesses and estimates—'guesstimates'—derived from available information at the time. It should however be appreciated that although these 'guesstimates' are reasonable indications, their information base is rapidly changing as more data are obtained and our understanding of the atmosphere-ocean-biota interactions improves.

In the following paragraphs, predictions on the Kenyan carbon dioxide contribution will be made on the basis of recent estimates, which are available in the literature. It is almost impossible to give a fair review of what is happening in each country in Africa and therefore the Kenyan case is presented as an example of Sub-Saharan African situation.

Globally, the developing countries contribute about 15 % of carbon dioxide emitted to the atmosphere. Thus, from a global perspective, CO_2 emission from a single developing country like Kenya would seem to be insignificant. We must however remember that atmospheric pollution protection and hence protection of the climate is the responsibility of all countries in the world and it is this combined concerted effort that will save the world. Like in most parts of the world in recent years, the seasons in Kenya seem to be shifting unpredictably and the rains becoming less reliable. This may be the result of a global climate change due to increased greenhouse gases in the atmosphere! Malaria-carrying mosquitoes, which were once confined to the hot lowlands around Lake Victoria and the coastal strip have appeared in the highlands of Kenya, which were known to be too cold for the insects. Clearly these highlands are either warming up or the mosquitoes have adapted to the cold climate.

It is known that the world is now committed to further warming due to increased greenhouse gases, which are already in the atmosphere. Carbon dioxide is one of the most important of these greenhouse gases, and in Kenya, its atmospheric concentration is enhanced, mainly by direct burning of fossil fuels, deforestation, and wood fuel consumption. Kenya depends very heavily on these sources of energy. Wood energy is the most important source of energy, accounting for nearly 72 % of all energy use with a large proportion of the population depending on wood fuel and charcoal. Most wood in Kenya is used for household cooking and space heating. This traditional application of wood fuel is a major source of CO_2 emission, which is further enhanced by the high rate of wood fuel consumption which exceeds replenishment. This is compounded by the fact that Kenya has a very small area of forest cover compared to the total size of the country. The total area of Kenya is 560,186 km^2 out of which 11,239 km^2 is water surface (rivers, lakes and part of the Indian ocean coast line of about 400 km). Only about 15 % of the total land area is used for intensive agriculture and supports about 65 % of the rural population [26]. It is in these small areas of Kenya where most forests are found.

High population growth rate coupled with high fuel wood demand and various changes in land use are causing deforestation, which leads to a reduction in the size of the already small forest cover. Deforestation increases CO_2 emission in three ways: first, forests act as sinks for CO_2 much of which is stored in the soil; second, the process of decomposition of forest materials produces CO_2; and third, the burning of wood is accompanied by large CO_2 emissions.

In 1988 an estimated total of 101,000 m^3 of fuel wood and charcoal was consumed in Kenya while 780,000 m^3 of timber was used for other purposes such as construction and paper production [6]. These figures were obtained from the commercial sector. However, the vast majority of wood is used as fuel wood and construction material through non-commercial channels.

Actual fuel wood consumption in Kenya is therefore estimated at about 0.6 tons per year per person. For a population estimated to be about 31 million in 2005, the total annual fuel wood consumption is about 18.6 million tons (1 m^3 of fuel wood is approximately 0.7 tonne), while to meet the demand Kenya would require over 30 million tons.

Another major source of CO_2 emission is from the burning of fossil fuels. In 1988 Kenya imported about 2,022,000 tons of crude oil which was refined in the country. Out of this, domestic petroleum fuels consumed was about 1,730,400 tons. Transport sector (road, marine, rail and aviation) is the main consumer of petroleum fuels taking about 1,165,000 tons in the same year and thus accounting for about

67 % of the domestic petroleum fuels. Industrial application accounted for about 25 %. Within the transport sector, road transport is the principal consumer of petroleum fuels and this is one area that needs to be seriously considered in order to reduce CO_2 emission into the atmosphere.

It is interesting to note that while crude oil importation remained fairly constant between 1984 and 1988, the proportion used in transport steadily increased from about 1,029,000 tons in 1984 to 1,165,000 tons in 1988. This was due to an increase in the annual number of newly registered vehicles from 15,694 in 1984 to 18,764 in 1988. It appears that the energy conservation achievements scored by industry and other government machinery were consumed by increased activities in the transport sector. Currently these figures are much higher as can be derived from data given in this book.

Despite availability of information on the use of fuel wood and fossil fuels, it is not possible to make an accurate assessment of the amount of carbon dioxide emitted by these sources per year and hence the magnitude of its impact on the environment can only be estimated. One thing is nevertheless clear: the rate of carbon dioxide emission into the atmosphere must be restricted to manageable and environmentally safe levels. This is particularly important in Kenya where the forest cover is estimated to be only 5 % of the total land area.

Carbon production from fossils fuels as per 1988 oil consumption of 1,730,400 tons using conversion factors recommended in the literature is 1.5×10^6 tons, which is equivalent to 0.0013 ppm increase in carbon dioxide in the atmosphere.

Cement production is another source of carbon dioxide. The annual production of cement from the two plants that existed in Kenya in 1988 is 1.5×10^6 tons. This gives an estimated emission of 2×10^5 carbon with carbon dioxide concentration of 0.00005 ppm. A third cement plant, which has been commissioned, has raised cement production level to more than double the 1988 figures. Thus the production of carbon from this activity is estimated to have increased two-folds by 2005.

Terrestrial emission from deforestation and other types of vegetation and wetland drainage cannot be predicted from available data as they depend on the type of vegetation, rate of destruction/decomposition and wetland drainage. Forests and other types of vegetation also function naturally as net carbon sinks because the production rate of organic matter exceeds the rate of decomposition. Surface water masses also absorb and store CO_2. The present uncertainties with estimating carbon dioxide absorption/emission rates by the biosphere, and lack of adequate information on the Kenyan situation make it difficult to quantify the CO_2 cycle in the biosphere. Consequently, in giving the data for carbon dioxide emissions in Kenya, it is assumed that all the un-accounted for CO_2 sources, such as decomposition of biomass materials, marine productivity, charcoal production and changes in land use, and carbon dioxide sinks such as surface water masses, forests and grasslands, balance each other and are therefore not considered in this analysis. These projections are therefore associated with uncertainties. Thus for the purposes of this analysis, the atmospheric carbon dioxide increase attributed to Kenya is linked to the combustion of oil and wood fuels (including charcoal) and the production of cement which produces a combined annual total of 6.87×10^6 tons of carbon. This is equivalent to 0.0018 ppm annual increase in CO_2 in the atmosphere. In global perspective, this is only about 0.1 % of the total annual global atmospheric CO_2 increase of 1.5 ppm—too small to warrant a national effort unless it forms part of a wide international or worldwide undertaking. Thus the calculated annual contribution of Kenya to the global increase in the concentration of carbon dioxide is small compared to those of a developed region and the World. The Kenyan estimates as well as the others based on contributions from fossil and wood fuels and cement disregard unaccounted for CO_2 sources and sinks. Carbon dioxide emissions from the three major sources discussed above are very closely associated with population growth and therefore the situation is expected to change in future.

In order to predict the future situation, it is necessary to define the atmospheric increase of CO_2 in terms of the per capita Kenyan contribution, which we estimate for 1989 to be 0.286 tons. This is 25 % of the global average per person carbon dioxide emission of about 1.16 tons. The population of Kenya would double by 2020 if the annual population growth rate remains at the present level of about 3 %.

Consequently, with the present trends of CO_2 emission remaining unchanged, the total CO_2 production in Kenya will also double. This projection still gives an insignificantly small quantity of CO_2 emission in Kenya. It however, does not consider industrial expansion and deforestation as a result of new human settlements, construction and grassland conversion into agricultural land. But even if it did, the figure would still be small. The important fact to note here is that although CO_2 emission from some developing countries is negligible, the net carbon dioxide emission into the atmosphere will continue to increase and may increase beyond the predicted level if nothing is done to change the trend. Industrialised countries have in the past emitted large quantities of carbon dioxide into the atmosphere and continue to do so in spite of the many international CO_2 control agreements. For example, the state of Michigan with less than half of the population of Kenya had a total annual CO_2 emission rate of 4.26×10^7 tons of carbon in 1987. This was about 6.2 times more than the total CO_2 emission in Kenya. On the other hand, total CO_2 production due to wood fuel consumption in Kenya was 1.7 times higher than that of Michigan (8,540,500 tons), a fact which underscores the significance of wood fuel as a major CO_2 source in Kenya as in other developing countries [26].

Globally, the atmospheric carbon dioxide concentration has already increased during the last 100 years due to human activities, especially industrial development, burning/combustion of forests and other biomass materials, and energy consumption. This has caused the Earth to warm up by an average of 0.5 °C and, in fact, the Earth is already committed to further warming due to the already accumulated greenhouse gases in the atmosphere.

It should be recognized that the atmospheric concentration of these gases will, in all likelihood, continue to increase resulting into a very destructive effect on the climate and global ecosystem. In recent years, many parts of the world, including Kenya, have more frequently experienced ‘natural’ occurrences including ecological changes and climatic disorder, which probably could be initial consequences of the global warming.

There is only one global atmosphere and it belongs to all nations of the world. Atmospheric pollution in California or Scotland will affect Kenya or any other part of the world. Every nation must therefore join in the worldwide effort to protect the atmosphere in order to maintain a habitable world.

Tropical rainforests, which are mostly found in the developing countries, seem to have the most intense rates of carbon recycling and their conservation upgrading of productivity will go along way in the management of the global carbon dioxide problem. It is clear that biomass is an important source of energy in Kenya as has been discussed elsewhere in this book and this is typical of most developing countries. For example, in 1988/89, the world's energy consumption was estimated to be about 3×10^{20} j out of which oil contributed 39 % while biomass (90 % wood) contribution was about 14 %. In developed countries 45 % of the energy was supplied by oil, 26 % by hydropower, 3 % by nuclear and only 1 % by biomass. But in developing countries, 44 % of energy came from biomass and 24 % from oil. These contributions vary from country to country but globally they imply that about two billion people totally depend on biomass energy. It is therefore possible to balance their contributions to the global carbon cycle by ensuring that production equals or exceeds consumption. To do so will require a concerted effort on the part of all peoples to adopt energy policies consistent with sustainability of supply through the continued development of renewable resource technologies [26].

2.10.2 Measures and Options

Kenya, along with other countries in East Africa, has realized the need to control CO_2 emission and is making an effort to reduce the problem. Kenya recognizes the important role of forests as a CO_2 sink and is emphasizing forestation measures as a priority objective for facilitating sound environmental conservation. The Rural forestation and Extension Services has continued to implement forestation programmes with the aim of sustaining a balanced ecosystem while making available forest products to meet the varied demands. In addition, agro-forestry has also been encouraged.

On the control of CO_2 emission from the burning of fossil fuels, the government is encouraging conservation activities. However, at the moment there are no strict measures to ensure that forestation and conservation activities are undertaken. The National Environment Secretariat (NES), which was formed to coordinate environmental protection activities has been carrying out environmental education and information activities, village assessments, and a national plan of action to combat desertification and to control pollution. National Environment Secretariat was eventually transformed into National Environment Management Authority (NEMA). Similar programmes exist in Uganda and Tanzania.

To reduce the emission of carbon dioxide from energy sources, the governments should recognize the risk to health and the dangers of global warming due to energy derived from fossil fuels and fuel wood. Strict energy efficiency and conservation measures must be applied in order to reduce atmospheric pollution by carbon dioxide. Since transportation activities in East Africa are the single largest source of CO_2, a reduction of emissions can be made through a combination of more stringent emission limitations for cars, buses, and trucks, strengthened inspection and maintenance procedures, and the use of clean fuels in commercial and private vehicles. Measures that would reduce unnecessary use of vehicle and improve traffic flow would help reduce CO_2 emissions. Some of these measures include greater use of public transport, high charges for parking space and good plan for non-motorized vehicles (bicycles) on all new roads. Efforts to implement these measures in the future should be seriously considered.

In addition to these measures, provision of energy must be carefully planned and effectively implemented. In this regard, renewable energy should be developed to reduce large scale use of fossil fuels. Many developing countries including those in East Africa are located within the tropics where there is abundant solar energy throughout the year. Solar energy technologies for the supply of electricity and heat energy would therefore be a very suitable option for these countries. So far the use of solar water heaters is rapidly gaining popularity in East Africa. Photovoltaic panels (solar cells) are also in the market but customer response is still very poor. Perhaps the government should introduce legislation regarding the use of solar energy in all new establishments (building, industries, etc.). Wind energy is another renewable energy, which has some potential in the region. There are a few local firms, which are already manufacturing and marketing wind energy devises. However, the use of renewable energies, in general, is still less than 0.1 % of the total national energy consumption.

Non-governmental organizations have been supporting governments' efforts by promoting energy conservation and the development of renewable energy technologies. This support should continue and, where possible, should encourage the highest standards of pollution control in industries and in the transport sector, and promote the adoption of life styles and technologies, which are consistent with sustainable development for all nations. East Africa in its desire to use more energy for development should do so while taking precautions to avoid mistakes made by already industrialized countries in order to limit the amount of greenhouse gases emitted into the atmosphere.

2.11 Concluding Remarks

This Chapter has given some important information about East Africa and has highlighted existing energy management practices and choice factors with regard to commercial and non-commercial energy resources. The East African energy use pattern is compared with the global energy consumption pattern. Further, the East Africa's prominent energy resources have been identified. A number of these are locally available while others are imported into the region. The traditional three East African states of Kenya, Uganda and Tanzania are all endowed with renewable energies but there are variations with regard to the quantities and availabilities of some energy resources such as geothermal, coal, oil and natural gas.

Having also identified the prominent energy resources and noting that most of the locally available resources have not been developed, this Chapter has attempted to expose the potential of various energy resources. It is evidently clear that only a small quantity of locally available energy resources have been developed in the region. There is still enormous quantities of various energy resources, particularly renewable energy resources, that are yet to be exploited. The main problems are mainly associated with the low level of local technological capacity in renewable energy technologies and the apparent complacency and hence inadequate support for energy development initiatives. Furthermore, information on specific energy sites including their commercial viability that could guide potential investors is not readily available.

Proper energy planning in the region is evidently far from adequate. Various energy issues including some energy resources are still under government departments that are not concerned about energy problems. This is making it difficult to formulate clear energy policies since the departments have their priorities in different issues. In this regard, energy provision policies are not well coordinated and hence very difficult to implement. The fact that some energy resources are not commercially recognized at the national level creates an imbalance in the level of support given for the development of different energy resources. The tendency therefore is to unnecessarily put more emphasis on control and management of commercial energies that are of economic interest to the nation. The sad thing about this is that commercial energies such as oil and grid electricity benefit only a small fraction of the total population.

The development of energy resources is to a large extent dependent on technological knowledge base required for innovativeness and scientific ability to adopt new energy technologies to suit local circumstances. Energy provision is by nature an expensive service and therefore the consumers must have the economic power to afford it. Chapter 6 presents basic scientific and technological information required for the development of various energy resources and describes the processes of producing different energy conversion devices. The information, on one hand, provides the justification as to why these conversion devices are expensive and, on the other hand, allays the fear in developing countries that these processes are too complicated and therefore not easy to accomplish under the prevailing local circumstances. This Chapter is intended to encourage researchers and policy makers to direct more attention and energy in the development of locally available energy resources. In this regard, a deliberate attempt has been made to limit theoretical knowledge in favour of more practical information. Theoretical knowledge is however provided where it is considered necessary in order to appreciate practical aspects.

Finally, the development, use and consumption of energy produce various types of wastes, which are normally discharged back into the environment. These wastes, if not properly managed or controlled, have very undesirable impact on the environment. This Chapter discussed the status of renewable energy in East Africa, general impact of energy on the environment and possible measures and options available.

References

1. Anderson, D. (1986). Declining tree stocks in African Countries. *World Development 14*(7), 853–863.
2. Aseto, O., & Ong'ang'a, O. (2003). *Lake Victoria (Kenya) and its environs: Resource, opportunities and challenges*. Kendu Bay, Kenya: Africa Herald Publishing House.
3. Awange, J. L., & Ong'ang'a, O. (2005). *Lake Victoria. Ecology, resources, and environment*. Berlin, New York: Springer.
4. Bahati, G. (2003). Geothermal energy in Uganda: Country update. In *International Geothermal Conference, Reykjavik*.
5. Bhagavan, M. R., & Karekezi, S. (1992). *Energy for rural development*. London, UK: Zed Books Ltd.
6. Central Bureau of Statistics. (1989). *Economic survey*. Republic of Kenya.
7. Central Bureau of Statistics. (2001). *Economic survey*. Republic of Kenya.
8. Daily Nation Newspaper. (2013). Energy. October 28, 2013.
9. East African Community. (2004). Protocol for sustainable development of Lake Victoria basin. Published by the East African Community Secretariat.
10. East African Weekly Newspaper. (2006). Global Struggle. 9–156 October, 2006.
11. Energy saving stoves—The significance for Kenya, gtzpsda.co.ke.
12. en.wikipedia.org/wiki/energy in Kenya. Retrieved June 18, 2015.
13. Financial Standard, Kenya. (2006). Anxiety over heavy reliance on hydro power. August 8, 2006.
14. Goreau, T. J., & de Mello W. Z. (1988) Tropical deforestation: Some effects on atmospheric chemistry. *Ambio, 17*(4), 275–181.
15. Hall, D. O. (1989). Carbon flows in the biosphere: present and future. *Journal of Geological Society, 146*: 175–181 (London, UK).
16. Hankins, M. (1989). *Renewable energy in Kenya*. Nairobi Kenya: Motif Creative Arts Ltd.
17. http://1.bp.blog.com/-hwgGn3T09xU/T8HulFqpNCI/East_Afr_Map.jpg
18. Karekezi, S., & Kimani, K. J. (2004). Have power sector reforms increase access to electricity among the poor in East Africa? *The Journal of International Energy Initiatives, "Energy for Sustainable Development, 8*(4), 10–25.
19. Karekezi, S., & Ranja, T. (1997). *Renewable energy technology in Africa*. London, U.K: Zed Books Ltd.
20. Kimani, M. J., & Naumann, E. (1993). *Recent experiences in research, development and dissemination of renewable energy technologies in sub-Saharan Africa*. Kenya: KENGO International Outreach Department, Nairobi.
21. Manibog, F. R. (1984). Improved cooking stoves in development countries: Problems and opportunities. *Annual Review of Energy, 9*(1), 199–227.
22. Mapako, M., & Mbewe, A. (2004). *Renewable and energy for rural development in sub-Saharan Africa*. London, U.K.: Zed Books Ltd.
23. McNitt, J. R. (1982). The geothermal potential in East Africa. *Proceeding of the Regional Seminar on Geothermal Energy in Eastern and Southern Africa*, Nairobi, Kenya.
24. Musonye Ronald, independent newspaper, August 28, 2014.
25. O'keefe, P., & Raskin, F. (1985). Fuelwood in Kenya. *Ambio, 14*(4–5), 221–224.
26. Othieno, H., & Franz, E. (1989). *Report on the NGO conference and workshop on Prevention of Climate Change*. Rotterdam, The Netherlands: Stichting Natuur en Milieu.
27. Othieno, H. (1991). Alternative energy resources: The Kenya perspective. *Energy and the Environment*, 413–415 (ASHRAE, Atlanta, USA).
28. Othieno, H. (1993). Research and development in renewable energy technology in sub-saharan Africa. Renewable energy technologies in sub-saharan Africa. KENGO, Nairobi, Kenya.
29. Othieno, H. O., & Awange, J. L. (2006). *Energy resources in East Africa: Opportunities and challenges*. Berlin: Springer, ISBN 3-540-35666-5.
30. Renewableenergy.go.ke/index.php/content/46. Retrieved June 18, 2015.

31. Sparknet. (2004). Uganda Country Overview.
32. Sparknet (2004) Tanzania Country Overview.
33. Sparknet. (2004). Kenya Country Overview.
34. UNDP/World Bank. (1984). *Energy issues and options in thirty developing countries*. Report No. 5230.
35. UNEP. (1979). *The environmental impact of production and use of energy part I, fossil fuels*. Energy report series 1979.
36. UNEP. (1986). The state of the environment. Environment and health. UNEP Report 1986.

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