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Chair of Environmental Architecture
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PhD
RESEARCH THESIS

PHOTOVOLTAICS IN GOVERNMENT SERVICES IN RURAL AREAS OF TROPICAL DEVELOPING COUNTRIES: WITH SPECIAL CONSIDERATION OF EAST AFRICA and TANZANIA in PARTICULAR

by

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DEDICATION

This work is dedicated my dear departed loved ones,
my mother Ma Domitilla Mukakurasi, my father Ta William Kaiza Byabato,
and my sister Stella-Matutina Yakiilira
who did not live to see me finish it.

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Last but not least, I thank all members of my family, my wife, kids and other dependants, who endured my absence for four years as I pursued this work.

> Nations both rich in energy and in energy technologies are rare. Today, Switzerland, Japan and Germany, absolutely poor in energy sources inside their borders, belong to the wealthiest nations of the world. Energy technologies are [therefore] more important than energy raw materials. Energy policy is energy technology politics.
>
> Carl-Jochen Winter (2006)
> Senior Chairman,
> Int-l Hydrogen Associaltion

I. ABSTRACT

This work is intended to be a **policy reference paper** for governments of tropical Developing Countries aiming at stimulating interest in application of Solar Electric systems i.e. or Photovoltaics (PV), (either alone or in combination with other energy resources) in rendering their services to their people. It is a PhD research thesis presented at Dortmund University Germany. As summarised in its title **“Application of Photovoltaics in Government Services in Rural Areas of Tropical Developing Countries, with special consideration of East Africa and Tanzania as a typical example”** this work deals with analysis of the current practices and existing potentials in the application of Solar Electric Systems, i.e. Photovoltaics (PV), in the provision of Government services, especially in rural and disadvantaged periurban areas of Tropical Developing Countries, where conventional grid electricity is either currently unavailable or erratic and, therefore, unreliable. The major part of field studies for this work was conducted in Tanzania but there are few case studies from other countries as well. It started at the end of 2004 end ended in 2008. In this research, we have been able to show that **Photovoltaics (PV)**, either alone (**stand-alone or island PV system solution)** or in combination with other electric energy sources **(Hybrid PV systems)**, is not only possible but is also a viable way of providing electric energy for **Government Services provision** in tropical developing countries. The “other” electric energy resources combined with PV can include such renewables as wind, mini-hydro and biofuels such as plant oil from *Jatropha curcas* seeds, other biodiesels and bioethanol that can be used either alone or in combination with non renewable fossil fuels such as ordinary diesel and petrol in modified or standard internal combustion engines coupled to ordinary generators. It has been shown that use of these methods can enhance and simplify provision and administration of Government services in some areas especially where costs of grid extension are not justified by the existing electric energy demand, or other financial and logistical considerations such as those encountered in the running of a small power generation and distribution system in a remote area running purely on diesel and/or other fossil fuels alone, where bulk fuel and lubricants procurement, transport and storage as well as equipment maintenance, safety and security are associated with special hurdles. Crowning all those considerations is the global necessity to **preserve our earthly environment** by employing PV either alone or in combination with other renewable energy resources and energy efficiency measures as a **clean development mechanism (CDM)**, contributing to reduction in global **greenhouse gas (GHG) emissions,** while **enhancing people’s quality of life**, by **empowering their governments** to be able to effectively and efficiently guide and supervise their development towards achieving at least the **Millennium Development Goals (MDG’s)** by providing them with the required government services at **minimal cost to the environment**.

II. TABLE OF CONTENT

Summary of Chapter 1: Presentation of the background to this work, key concepts about developing countries, the tropics, government services and photovoltaics in relatively general terms. Problem statement about the energy, especially the inadequacy of electricity supply in developing countries. Presentation of the energy situation in developing countries, available alternative for electricity provision and the hypothesis that Photovoltaics technology is one the best ways of provision of electricity for high impact social areas such as provision of essential government services. Research objectives are stated here as aiming to improve the current state of government services provision through providing evidence to the effect that a little input in form of electric energy provision can have a big positive impact upon both the quality and quantity of such services provided. This will in turn inform policy and direct practice of their provision. Expected results of this work are also stated in this chapter**.**

1. INTRODUCTION

1.1. The energy picture in Africa, East Africa and Tanzania

Utilisation of energy is a basic requirement for development of an individual person, an industry, a government or a nation in general. There are many ways of looking at energy and its consumption. However, as relates to technological development, the most important classification is that of commercial and non commercial forms of energy, in which most of the energy utilised by underdeveloped tropical African countries is the latter, i.e. non-commercial energy. This group includes mainly primitive unprocessed and /or semi-processed forms of biomass such as firewood and charcoal. This means the underdeveloped world and especially Africa, (Tanzania included) is a very low consumer of commercial energy relative to other regions and this, in the opinion this author, is one of the reasons for underdevelopment or its major manifestation.

The world energy consumption picture is summarized in this quotation from the **Environic Foundation International (EFI):**

Of the 6 billion people living in the world, there are still 2 billion people (or 1/3 of the world's population) who lack access to commercial energy, most of whom live in severe poverty. At the same time, in the period between 1992 - 1999, total world consumption of commercial primary energy increased by almost 10% (Petroleum, coal and natural gas are the world's major primary energy sources; taken together hydroelectricity, nuclear, solar and wind power meet a small percentage of energy needs). One reason for this increase is the fact that developing countries' share of global commercial energy use increased to almost 30% in 1998 as compared to only 13% in 1970. On a per capita basis, however, the increase in primary energy use has not resulted in more equitable access to energy services between industrialized and developing countries. In Africa per capita energy use barely increased in the 1990s and remains at less than 10% of average per capita use in North America. Regional energy use is even more inequitable when viewed in terms of per capita electricity use. In the least developed countries, 83 kilowatt-hours per capita are consumed while in European countries 8,035-kilowatt hours per capita are consumed” *(EFI 2006)*.

At present, most of the energy used in Tanzania (about 90%) is in form of primitively processed biomass mainly firewood and charcoal, used principally for domestic purposes and some elements of mainly un-mechanised rural industry such as traditional salt preparation and burnt-brick production for building construction purposes etc.

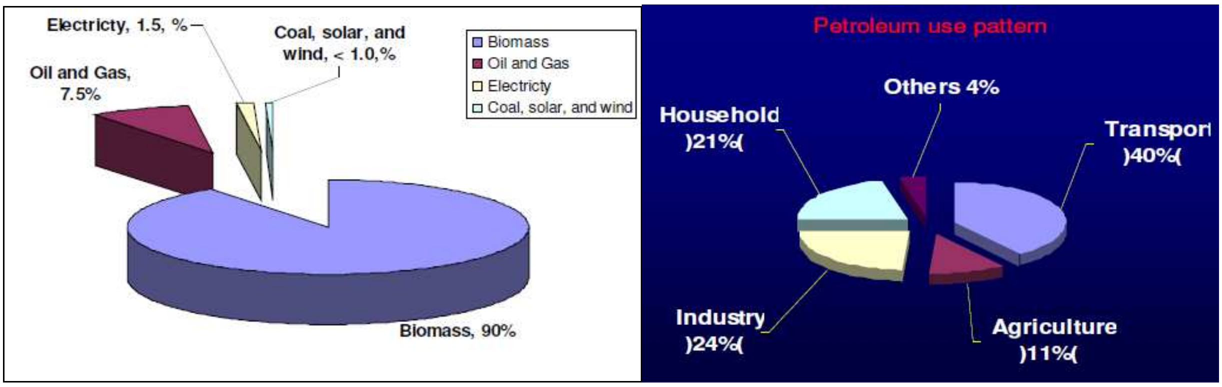
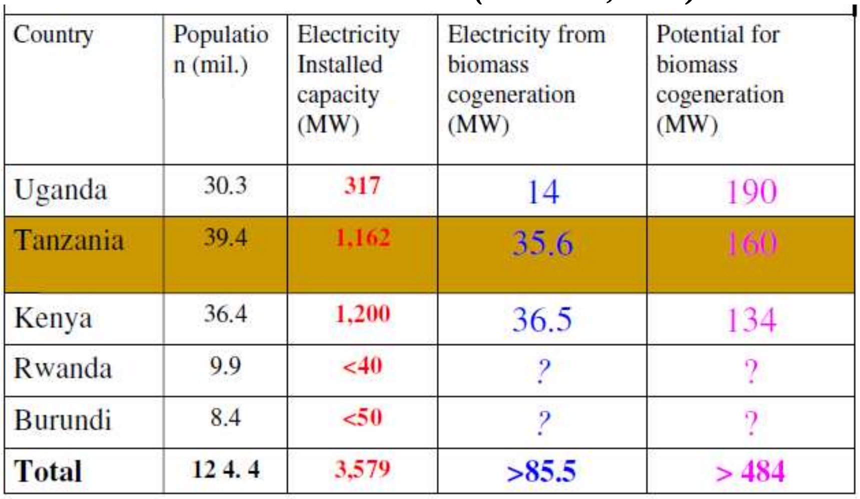


Fig. 1.1: Energy Sources & Petroleum Use Pattern in Tanzania by 2008 ***(Mwihava 2008)***

After biomass, fossil fuels, mostly liquid petroleum products and lately, to a smaller extent, natural gas, comprise the main commercial energy sources, in Tanzania. Petroleum products, mainly petrol and diesel are used mainly for mechanical transport and electric power generation, whereas kerosene is used directly for lighting and heat generation mainly for cooking and, to a lesser extent, in running of absorption cycle refrigerators, which are used principally for medical purposes, especially vaccine storage in the on-going child immunisation programs. To underline the importance of kerosene in lighting, the name for kerosene in many local languages can be literally translated as “lamp oil” (e.g. “*mafuta ya taa*” in Kiswahili or “*amajuta g’etara*” in Ruhaya).

This grim energy picture is true not only for Tanzania but is typical of Sub-Saharan Africa, with the “statistical exception” of South Africa. The phrase “statistical exception” is used to denote the fact that the South African energy picture is skewed by its relatively strong industrial base, but quite unfortunately, because of the Apartheid legacy, most of the people of South Africa do not live very differently from the rest of Africa, when one considers their domestic energy consumption pattern.

Table 1.1: Comparison current status and future of Biomass co-generation potential in East African countries ***(Mwihava, 2008)***



Country	Population (mil.)	Electricity Installed capacity (MW)	Electricity from biomass cogeneration (MW)	Potential for biomass cogeneration (MW)
Uganda	30.3	317	14	190
Tanzania	39.4	1,162	35.6	160
Kenya	36.4	1,200	36.5	134
Rwanda	9.9	<40	?	?
Burundi	8.4	<50	?	?
Total	12 4. 4	3,579	>85.5	> 484

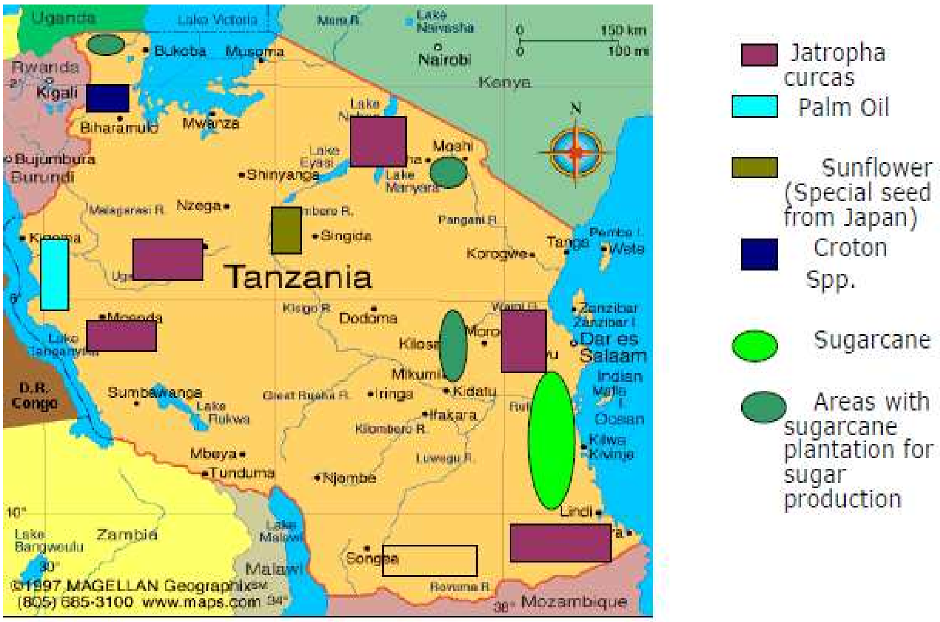
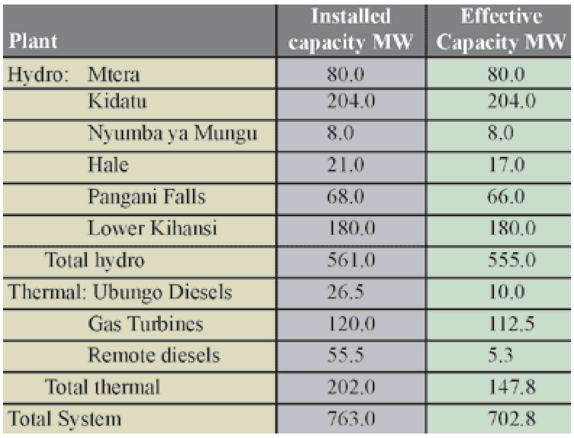


Fig. 1.2: Actual and potential source areas for modern commercial bio fuels in Tanzania *(Mwihava 2008)*

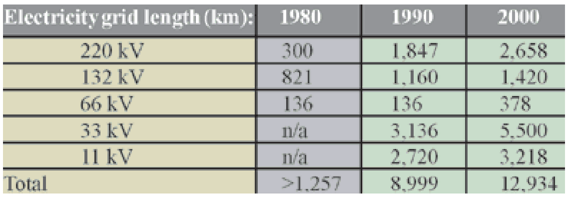
If development is to come, or if the United Nations **Millennium Development Goals (MDGs)** are to be attained, then a refocus on energy and its utilization pattern must be made. More electricity instead of raw or semi-processed biomass has to be used. One of the resources readily available to be exploited for electricity generation in tropical Africa is the Sun, i.e. Solar Energy, either directly through photovoltaics as well as high- and low-temperature solar thermal systems, or indirectly through energy plants e.g. *Jatropha curcas*, wind, mini-hydro or any combination of them.

1.2. Electricity generation and utilisation

Of all forms of energy, electricity occupies a special place as a key tool for industrial development of modern nations and societies. It is a foregone understanding that modern governments need electricity for their effective function in rendering their services to their citizens. In most cases, electricity is conventionally generated at a few centralised generating stations often far away from the user, and must then be modified, transmitted and distributed to where it is required for use. In Tanzania, for example, about 75% is generated from large scale Hydropower stations, such as Kidatu, Mtera, Hale, Pangani, Nyumba ya Mungu, with most of the remaining coming mainly from isolated diesel generating stations. The power station at Kiwira Coal Mines is the only coal fired power station in Tanzania. Following commencement of exploitation of local natural gas reserves in more recent times, two gas turbines located at Ubungo in Dar es Salaam, have been added to the national power array of Tanzania. Major conventional electricity generation, and all electric power transmission and distribution in Tanzania is currently run by the Tanzania Electric Supply company (TANESCO), which is still a state monopoly utility company although plans are currently under way towards its privatization probably after its unbundling into separate generation, transmission and distribution companies. The Kiwira power station supplies its surplus power to the Kyela and Tukuyu towns through power sales to TANESCO. Currently, the only sizeable private commercial power generation business is the Independent Power (Tanzania) Limited (IPTL) which generates power from Wärtsilä medium to high speed diesel generators but also supplies all power it generates to TANESCO through a controversial power sales contract.



Plant	Installed capacity MW	Effective Capacity MW
Hydro: Mtera	80.0	80.0
Kidatu	204.0	204.0
Nyumba ya Mungu	8.0	8.0
Hale	21.0	17.0
Pangani Falls	68.0	66.0
Lower Kihansi	180.0	180.0
Total hydro	561.0	555.0
Thermal: Ubungo Diesels	26.5	10.0
Gas Turbines	120.0	112.5
Remote diesels	55.5	5.3
Total thermal	202.0	147.8
Total System	763.0	702.8

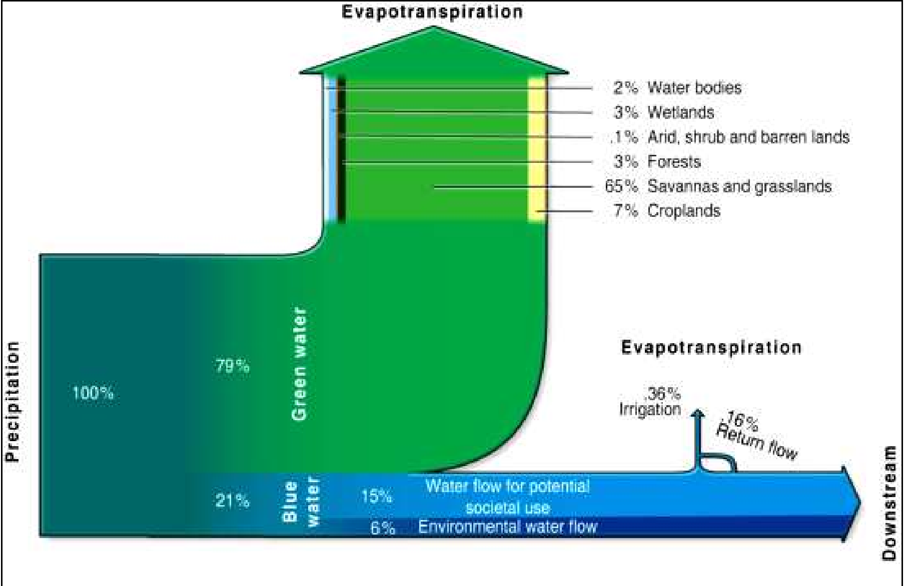


Electricity grid length (km):	1980	1990	2000
220 kV	300	1,847	2,658
132 kV	821	1,160	1,420
66 kV	136	136	378
33 kV	n/a	3,136	5,500
11 kV	n/a	2,720	3,218
Total	>1,257	8,999	12,934

Generation additions	MW	Year	Transmission line addition	kV	Km	Year
Ubungo CT unit 5	40	2004	Kinyerezi - Factory Zone	132	7	2004
Conversion of Tegeta diesels	-	2004	Iringa - Singida - Arusha	220	765	2005
Oil-fired combustion turbine	60	2004	Mtera - Singida - Arusha	220	665	2010
Kinyerezi CT	60	2005	Shinyanga - Mwanza	220	139	2010
Zambia interconnector	200	2006	Ruhudji - Mufindi - Kihansi	220	200	2012
Ruhudji hydropower	358	2010	Ruhudji - Kihansi	220	150	2012
Conversion of oil-fired CT	-	2016	Kidatu - Morogoro - Ubungo	220	310	2012
Mchuchuma coal-fired plant	200	2013	Mchuchuma - Mufindi	220	283	2018
Mchuchuma coal-fired plant	200	2020	Rumakali - Mbeya	220	85	2022
Rumakali hydropower	222	2023	Rumakali - Mufindi	220	134	2022
Combustion turbine	60	2026	Mchuchuma - Mufindi	220	283	2026

Fig. 1.3: Tanzanian conventional power generation, development and prospects by 2002 (Photo: Mtera Dam on the Ruaha river in South Central Tanzania) *(Mohammed Saleh 2002)*

The generated power is then transmitted to major city centres over a high voltage transmission system for local distribution. This involves costs, both fixed and variable (i.e. dependent on amount utilised) as well as many uncertainties depending on the vagaries of the weather. For example, since the early 1990's, almost each year now, Tanzania has been experiencing several months each year, of power shortages due to insufficient water levels in the power generation dams as a result of ever more severe draughts. These power shortages have been necessitating blackouts and power rationing for several months each year with great loses in every sphere of the already weak national economy, including government services provision in the few areas where power dependent facilities are already in place. The year 2006 had the worst experience with power rationing that lasted from February to December and that had been extended to having no electricity in all places for over 12 hours per day (most of it during daytime) everyday of the week for over 5 months. According to *Churi (2006)*, by February 2006, hydro electricity generated in Tanzania had dropped to 50.5 MW from the original 561.0 MW installed capacity. The Mtera reservoir which, under normal conditions held about 80% of Tanzania's water reserves designated for hydropower generation, was at a low level of 687.42m above sea level instead of the normal 690m and was not expected to fill up during the then expected "long rains season" *(Masika)*, supposed to end in May 2006. Indeed, as reported by *Mbwambo (2006)***,** by May 2006 the situation had not improved and was again not expected to improve because the rain that fed seasonal rivers that normally fed the Ruaha river, were observed to be failing and the Ruaha was still dry even during the rainy season. Ruaha river is the source of the Mtera Dam and a main tributary to the Rufiji river. To make matters worse, a breakdown in one of SONGAS transformers, forced Tanzania's TANESCO had to increase the power cuts (politely called power rationing) from 8.5 hours to 11.0 hours per day. These problems associated with total reliance on water for power supply, are explained by the dependence of available water for Hydro Electric Power (HEP) stations on precipitation, as the diagram below indicates. The diagram shows that water for HEP is only a small part of the 15% of precipitated water, where the great bulk of it (approx. 79%) goes back to the atmosphere through evapo-transpiration. The diagram produced by the Stockholm Energy Institute (SEI) was quoted by *Ahlenius (2006)* in connection with water supply for Nigeria, but it serves as a good example for many tropical countries with similar conditions, including Tanzania and the East African region in general.



Source: Stockholm Environment Institute. *Sustainable Pathways to Attain the Millennium Development Goals Assessing the Key Role of Water, Energy and Sanitation*. 2005.

Fig. 1.4: Proportion of available water resources used in power generation

In addition to the foregoing, quite unfortunately, however, conventionally generated electricity is not available everywhere in tropical developing countries and prospects for realising this are made even more difficult by the fact of current commercialisation of electricity supply where investment is controlled by the profit motive. Taking Tanzania as a typical example of a tropical developing country, a recent project paper for the **Global Environment Fund (GEF)** put the percentage of Tanzanian Population connected to electric mains grid at less than 10% nationally and at only 1% in rural areas where about 75% of the Tanzanian population lives. Under such conditions, without adequate electric energy supply, governments, both central/national and local, or their executive agents, find it difficult to render their services to the public, because they cannot use modern tools in performing their functions. Because of this, third world governments seem ineffective or at best very slow in rendering their services to the public.

As presented in *Meena (2003)***,** the environmental argument in building the case for PV is weak when considering only green house gas emissions in this part of the world. Most of the greenhouse gases in East Africa do not come from power generation, but from "other energy" mainly transport and other industrial and domestic use. However, this pattern is bound to change as more and more people get access to conventional electricity. At this stage of their technological development, the main argument for PV in tropical developing countries, including East Africa and Tanzania in particular, is mainly economic.

1.3. Keywords and Concepts

1.3.1. Photovoltaics (PV)

Photovoltaics is the art, science and technology of obtaining electric energy directly from light. This is usually achieved by shining light onto a layer (or set of layers) of specially prepared light sensitive material which is wired to detect this energy and/or incorporated into an electric circuit enabling utilisation of this energy. The sun being the main source of light, the practical application of the science of photovoltaics is to generate usable electricity from sunlight. As a result, we get the terms, Solar Electricity, Solar Electric Technology, Solar Photovoltaics (Solar PV). Nowadays, in most usages, people simply use the term “Photovoltaics” or “PV” to denote “Solar Photovoltaics”. In some cases some people use the term “Solar” or “Solar Energy” to denote “Solar Photovoltaics”, however, it is important to note here, that the concept of **solar energy** is much broader than photovoltaics as there are other ways of getting useable energy from the sun’s radiation. Some of this energy may also be converted to electricity using conventional principles in solar-thermal power plants. As photovoltaics is the main concern of this thesis, a more detailed treatment of this concept comes later on in this thesis.

1.3.2. The Tropics and Tropical Countries

From our basic Geography we know that **the tropics**, *(Tropic of Cancer and Tropic of Capricorn)*, are latitude lines 23.5 degrees to the North and South of the Equator respectively, representing the Northernmost and the Southernmost areas where the sun may shine overhead at noon, for a certain time in a year. All locations on Earth in between these two lines, including the Equator, are collectively called “Tropical Areas” or also “The Tropics”. In climatically terms, the term “Tropical areas” includes areas slightly beyond the tropic lines as indicated by *Ssengooba-Kasule (2003)* on the map (Fig. 1.5) shown hereunder. For the purpose of this treatise, we take the latter meaning.

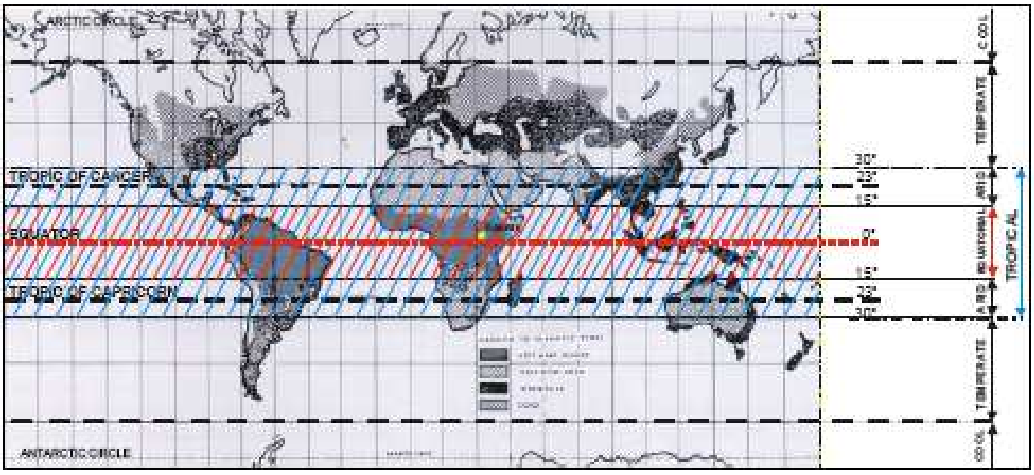


Fig. 1.5: Tropical countries *(Ssengooba-Kasule 2003)*

The countries in this area are thus called “Tropical Countries”. From the Solar Energy point of view, they are characterised by the following factors:

1. Special **solar geometry** with the solar path nearly always through the **zenith**.
2. A seasonal **solar declination range** spanning **both North and South** orientation, as distinct to the situation in temperate lands where the although declination angles vary annually but orientation remains fixed only in one direction, towards the equator, i.e. either South (for Northern Temperate Zones of Eurasia and North America) or North (for Southern Temperate Zones, e.g. Australia, New Zealand, or southern tips of the African and South American continents).
3. Relatively **high solar Radiation intensities** compared to similar values in temperate zones at most times due to the special Tropical Solar Geometry indicated in (1) above.

4. An almost annually **constant daytime duration** (approx. 12 hours) which is always almost fairly equal to night time, i.e. equal division between daytime and night time with 12 hours each, as distinct to the situation in temperate zones with large seasonal fluctuations in daytime duration (c.f. Dar es salaam: Daytime duration 12-12:30 h/day all year round vs. Dortmund: Daytime duration: 6 h/day in Winter- 16 h/day in summer).
5. A **narrow annual temperature range** at any given place.
6. A similarly **narrow daily temperature range** at the same places.
7. Humidity **based annual climatic seasonal regime**: wet (rainy) season– dry season – wet (rainy) season dry season rather than a **temperature based** one experienced in the temperate climates i.e. winter-spring-summer-autumn.

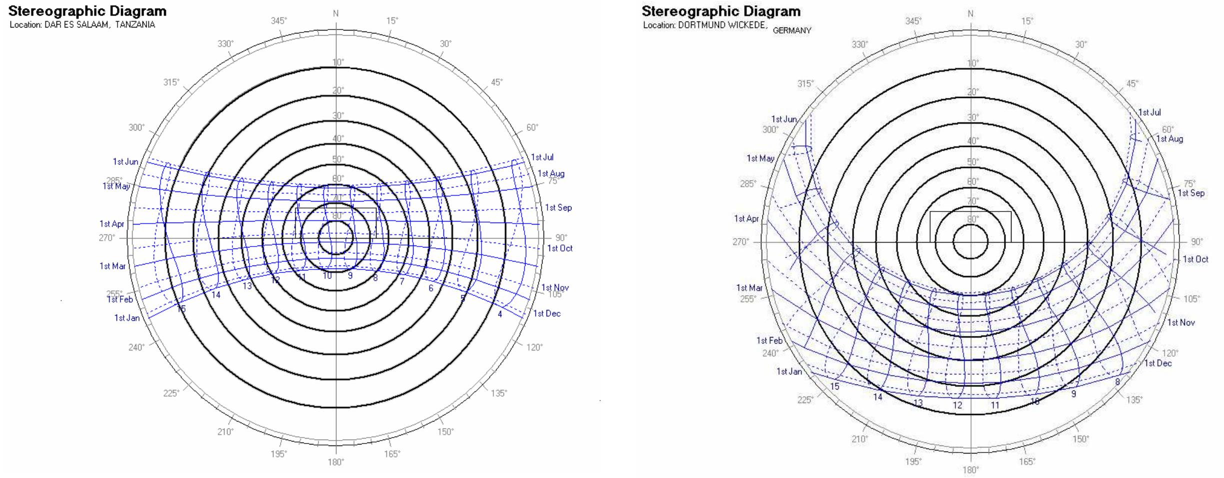
These parameters are summarised in Table 1.2 and Fig. 1.6

Table 1.2: Solar and Environmental Parameter Comparison between Tropical and Temperate Zones, (using Dar es Salaam and Dortmund cities as typical examples)

Parameter	**Tropical Zone** **e.g. Dare es Salaam, 6°S**	**Temperature Zone** **e.g. Dortmund, 51.31°N**
Solar path	Near Zenith path	Never through the zenith
Solar declination	Seasonal declination orientation variation from North to South	Seasonal variations in the maximum angle of Solar declination in a constant orientation towards the equator (South)
Solar Radiation Intensity	1773 kWh/m² a	1050 kWh/m² a
Daytime duration	Narrow Range 12h/day (+/-30 min.)	Wide range
Temperature Range (Annual)	Narrow +20°C +30°C	Wide -20°C (Winter) +30°C (Summer)
Temperature range (daily)	Narrow +20	Narrow
Seasonal variation basis	Humidity based (Wet-dry)	Temperature based (Hot-cold)

Table 1.3: Comparison solar radiation data for cities in tropical and temperate zones using examples of Dar es Salaam and Dortmund respectively. (Source: METEONORM 5.0)

Month	Solar Radiation Data for Dar es Salaam (Horizontal)				Solar Radiation Data for Dortmund (Horizontal)			
	Mean air temp **Ta** [℃]	Diffuse radiation **H_Dh** [kWh / m²]	Direct radiation **Bh** [kWh/m²]	Global radiation **H_Gh** [kWh / m²]	Mean air temp **Ta** [℃]	Diffuse radiation **H_Dh** [kWh/m²]	Direct radiation **Bh** [kWh / m²]	Global radiation **H_Gh** [kWh / m²]
Jan	27,8	89	69	158	2	14	5	19
Feb	28,3	83	64	146	2,8	25	12	37
Mar	27,8	83	62	146	5,7	41	22	63
Apr	26,7	77	42	118	9,5	64	43	107
May	25,6	72	65	136	13,7	84	57	141
Jun	24,4	65	66	131	16,9	91	42	134
Jul	23,9	65	73	138	18,4	93	51	144
Aug	23,9	81	68	149	18,3	81	41	122
Sep	24,4	75	73	148	15,4	49	29	78
Oct	25,6	89	75	164	11,2	35	15	51
Nov	26,7	84	89	173	6,2	18	6	24
Dec	27,8	83	81	164	3,3	11	4	14
Year	26,1	945	826	**1771**	10,3	606	328	**932**



Dar es Salaam, Tanzania
a city in the Tropical Zone, 6° S

Dortmund, Germany,
a city in the Temperate Zone, 51.3° N

Fig. 1.6: Solar path diagrams showing typical distinctions between tropical and temperate zones.(once again Dar es Salaam and Dortmund as typical examples)

1.3.3. Microclimates in the tropics

Of course these “typical” characteristics may differ from location to location. They are usually modified by other **geographical factors** such as elevation, topography, exact location, proximity to big water masses, local geology. These in turn may result into special meteorological conditions such as Cloud cover, Prevailing Winds, Rainfall (duration, spread and intensity) which may further modify the “Solar Picture” of a given locality. In recent times some anthropogenic factors have also come into play, i.e. the local climate of a place may be modified by the human activity around that place. Human activity, in turn, is related to population density, size and other demographic, economic and geo-political factors. It now matters climatically, (especially in ambient temperature terms) whether a place is in a big city, small town or out in the countryside (rural area). Industrial activity, which is currently not very big in the tropics, may further complicate this picture. Industrial activity will further be examined further-on in the sub-heading characterising “Developing Countries”.

1.3.4. Tanzania as an example of tropical country.

The influence of all the above named factors are reflected in the climate of Tanzania as described hereunder and illustrated in table 1.3 the summary of average monthly temperature maxima and minima of some locations in Tanzania, in selected key months, as presented by the Tanzania business directory (2004)[4].

Table 1.3: Mean monthly maxima & minima of temperatures in some locations in Tanzania (in degrees Celsius)

CITY	JANUARY		APRIL		JULY		OCTOBER	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
D’Salaam	31.5	23.2	30.7	22.4	28.8	28.8	31.9	31.9
Arusha	28.1	13.7	25.2	16.2	21.8	21.8	27.2	27.2
Bukoba	26.3	16.1	25.8	16.9	25.4	25.4	26.2	26.2
Dodoma	26.3	16	25.8	17.0	25.4	25.4	26.2	26.2
Mbeya	23.2	13.5	23.1	12.1	21.7	21.7	26.8	26.8

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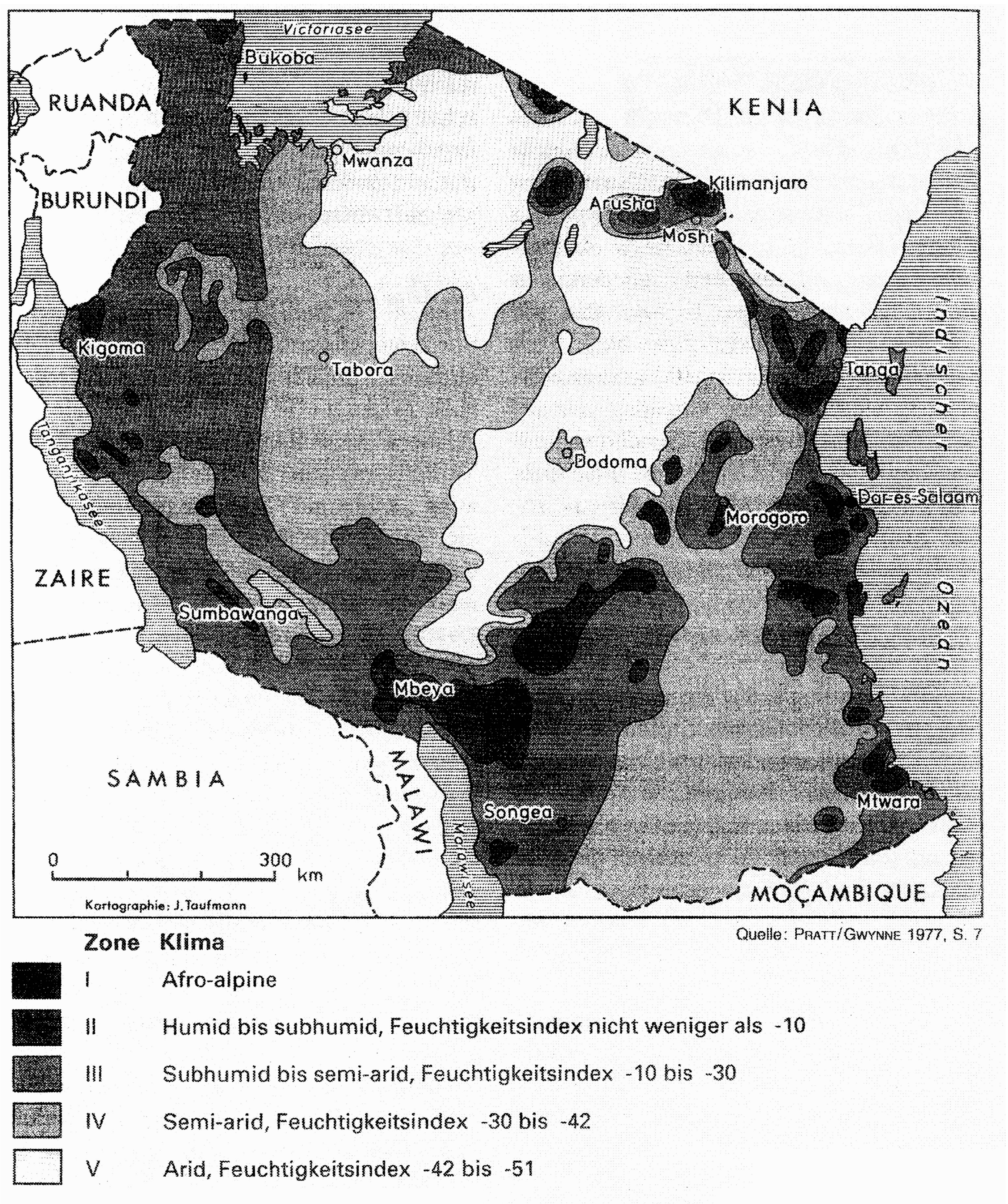
[4] Source: http://www.tanzania-online.gov.uk/Business/businessdirecto_/countryprofile/countryprofile.htm#climate (Part of the official website of the Tanzania High Commission in the UK & Ireland, London).

Climate:

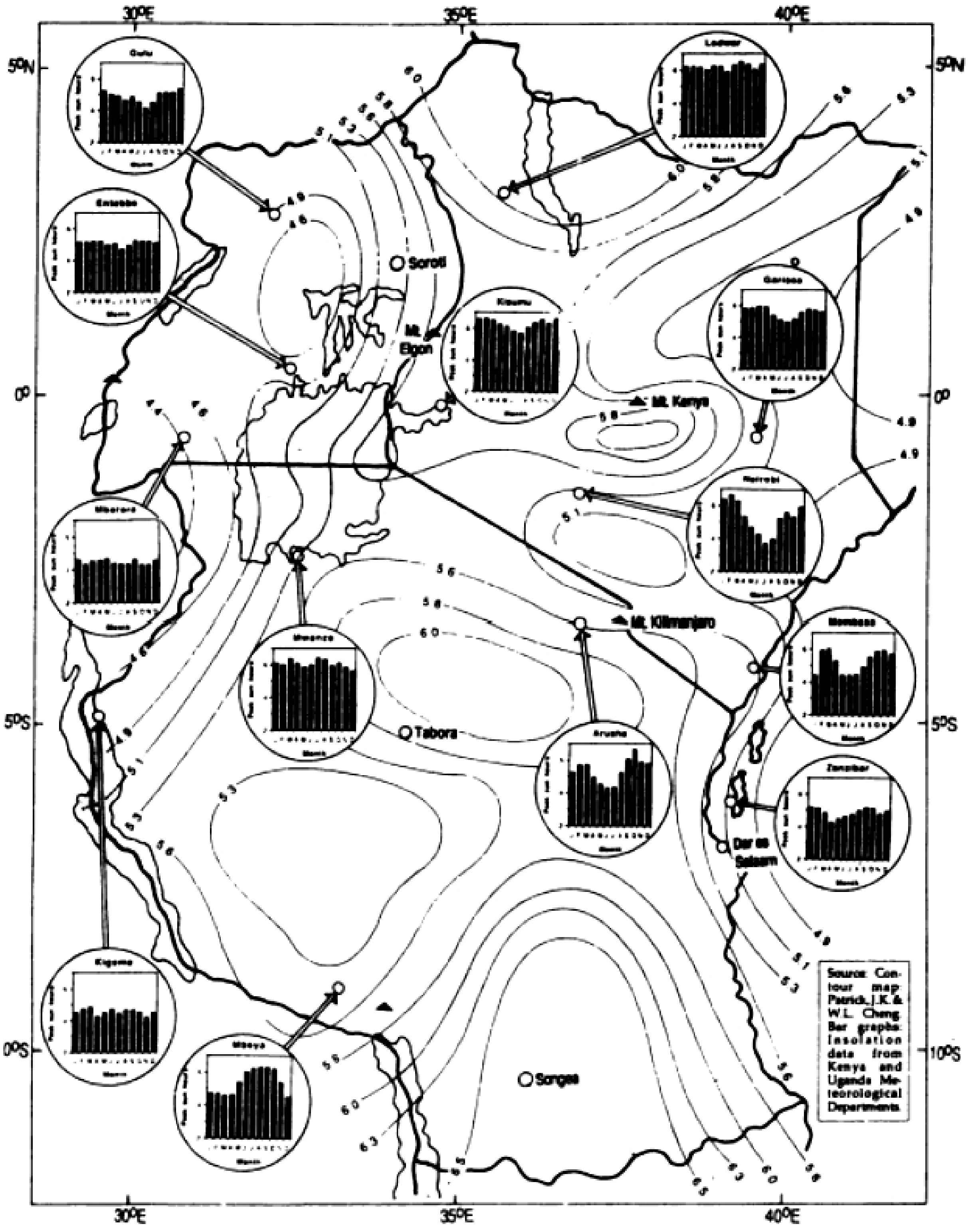
As stated before, Tanzania's climate and vegetation, influenced by humidity, varies with geographical zones. We thus have tropical on the coast, where it is hot and humid (rainy season March-May): semi-temperate in the mountains (with the Short Rains *(Vuli)* in November-December and the Long Rains *(Masika)* in February -May): and drier *(Kiangazi)* in the plateau region with seasonal variations in temperature (within tropical context). Total rainfall increases towards the north around lake Victoria. Rainfall is well distributed throughout the year reaching peak during the period of March and May. As a result, Tanzania is divided into local sub-climatic zones as follows: Lush tropical at the coast: forest and woodland covered 46% of the land in 1990 (a reduction of almost 6% by 1993!): in the previous 35 years, coverage decreased by an average 0.3% p.a. The rest of the country, apart from urban areas is savannah and bush. *Engelhard (1994)* calls them eco-climatic zones as shown Fig.1.8. with slightly different names, but essentially the same.



Quelle: Pratt/Gwynne 1977, S. 7

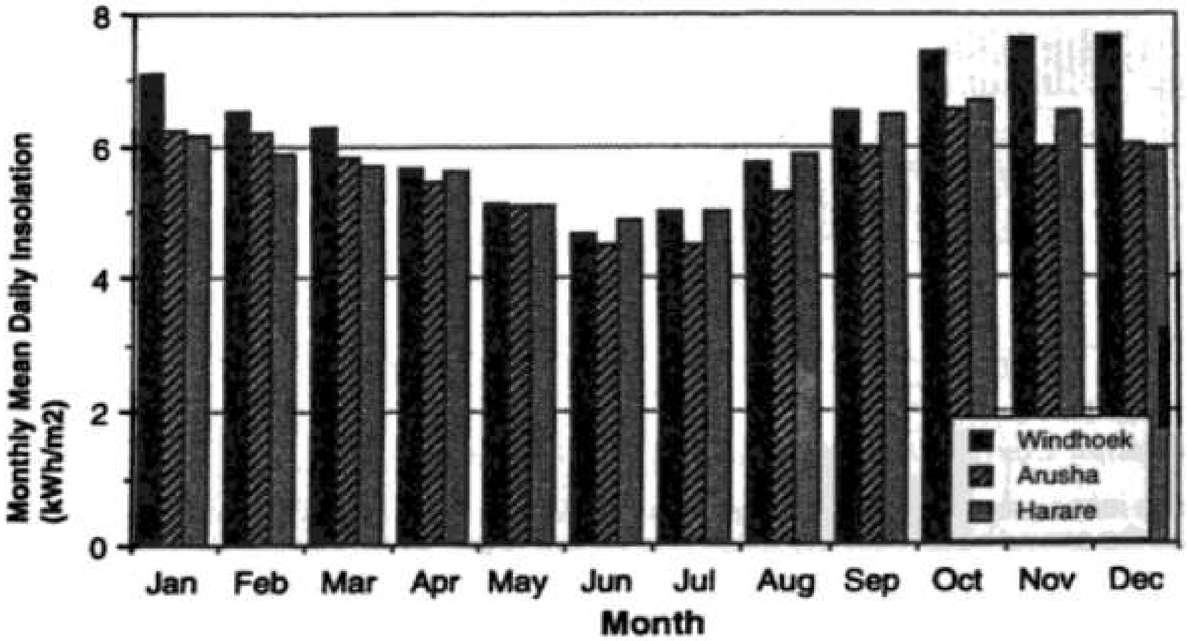
Fig. 1.7: Eco-climatic zones of Tanzania *Source: Engelhard (1994)*

Note: To illustrate the effect of humidity on tropical climate in general and local microclimates, two cities Bukoba and Dodoma, showing similar temperatures on table 1.3, belong to different climatic regions on fig.1.7 with quite different vegetations because of differing humidity regimes. In addition, humidity, cloud cover and rainfall also affect local insolation data. The solar radiation distribution in the region is shown in Fig.1.8 and Fig.1.9 as presented by Hankins (1995).



Source: Contour map: Patrick, J.K. & W.L. Cheng. Bar graphs: Insolation data from Kenya and Uganda Meteorological Departments.

Fig. 1.8: Solar Map of East Africa: contours show daily irradiation in "peak hours"/day (kWh/m²/day) *Source: Hankins (1995)*



Mean daily insolation by month in three African towns. The bar graph below compares solar energy availability by month in Windhoek, Arusha and Harare

Fig. 1.9: Monthly mean daily insolation for three cities (Arusha, Harare & Windhoek) in the Eastern and Southern African region. Source: Hankins (1995)

From the foregoing map and bar chart we see that the in general daily solar radiation in the region ranges from 4.5 to 6.5 peak hours/day, (4.5 kWh/m²/day -6.5 kWh/m²/day). From this information for purposes of solar energy installations calculations, (both generation and storage), prudently conservative estimates of 4.5 kWh/m²/day may be taken, for fail-safe stand-alone PV systems, with reasonably low energy storage capacity provisions. For PV-biodiesel hybrid systems with correspondingly even lower energy storage capacity, reasonable average estimates of 5.5 kWh/m2/day may be taken because in this case the power security role of energy provision at moments of very high power demand or critically low solar energy harvests is taken over by the bio-diesel generator, as will be seen later in chapter 4.

1.3.5. The Concept of “Developing Countries”

The term **“Developing Countries”** is a polite (political?) term used to denote **“Technologically Underdeveloped”** countries, otherwise generally called **“The third World”**. These countries are characterised by a number of Economic, Social and Political factors. Some of such factors are as follows:

- Low **industrialisation** levels
- Low **population densities** at national level (with a few exceptions)
- **High** general and infant **morbidity** and **mortality** rates
- **Low Per Capita Electrical Energy demand and utilisation**
- Low actual and perceived per-capita <u>**monetary**</u> **income**
- Low <u>**monetary**</u> purchasing power of the people

NB. Here the word “monetary” is underlined because it has a special significance. Money is used in the “modern” world economic circles as a measure of wealth, or “richness” of a physical or legal person (individual or organisation). In actual fact, however, it may be misleading when assessing the economic resources, and therefore, **purchasing power** of some third world people, most of whom live partly outside the world monetary system, for example many people in rural Tanzania. Besides cash money (in pockets or bank accounts), these people have many other "cashable" resources such as crops and livestock, which may be used in lieu of cash and, in some cases, to generate cash if and when these people have a necessity for purchase and if some elements of the economic infrastructure are modified to permit this. This issue has been discussed by many people including *Mwombeki (2005), Duodu (2005)***.** As observed during the recent world-wide financial market crisis of 2008, Africa and many other developing (read technologically underdeveloped or third-world) have not been gravely affected by this crisis because they operate mostly "outside" the world financial circles.

1.3.6. Sub-Saharan African underdevelopment reality (in traditional terms)

In general Tropical Developing countries, especially those in Africa, which comprise what is alternatively called Sub-Saharan Africa, have generally worse development indicators when compared to other regions of the world. According to World Bank sources, it is stated that

"… while peoples lifespan have been rising in the rest of the world, those in sub-Saharan Africa have been falling and the relative GDP remains low."

The following figures, from the World Bank's Regional fact Sheet from World Development Indicators 2007 will help to illustrate the point:

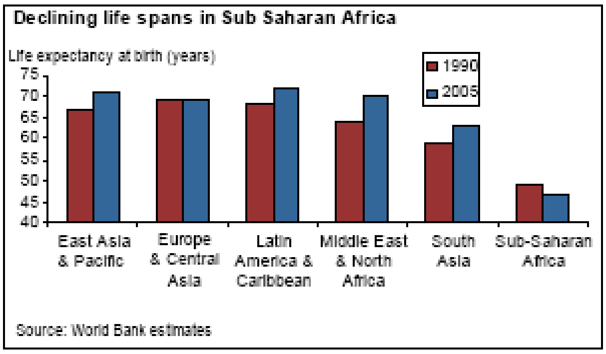


Fig. 1.7(a): statistical life expectancy data by regions

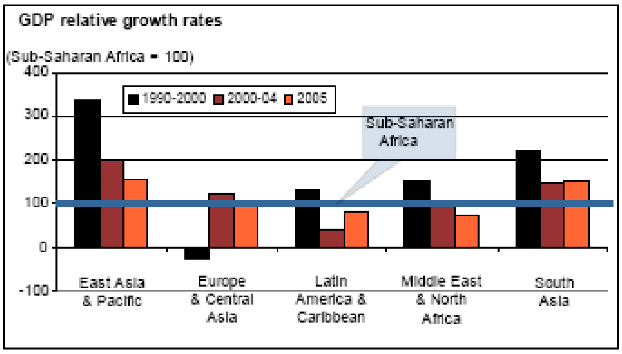


Fig. 1.7(b): Relative growth rates by regions

1.3.7. Sub-Saharan Africa's Positive Trends

Despite this grim picture, however, all is not lost. There are "rays of hope" if one pays the necessary attention and offers a genuine "sustainable helping hand" to Africa, in terms of **genuine technology transfer** and **genuine inclusion** in the world commercial system. In recent years there has been a sustained growth in Domestic Product (GDP). According to the *World Bank (2007)*, for example, in 2005 Sub-Saharan Africa's **GDP grew at 5.7%** thereby showing growth rate above 5% for the second consecutive year running. The figure hereunder graphically illustrates this growth tendency.

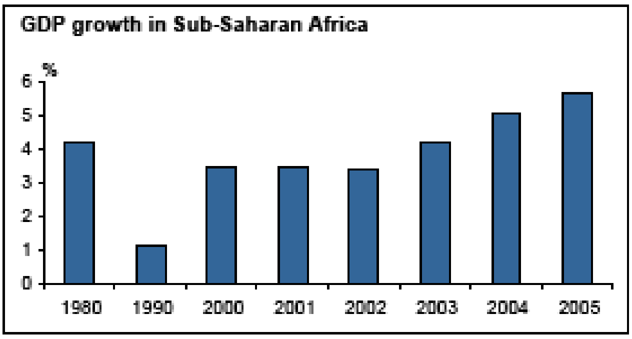


Fig. 1.8: Sub-Saharan Africa's positive GDP growth tendency in recent years

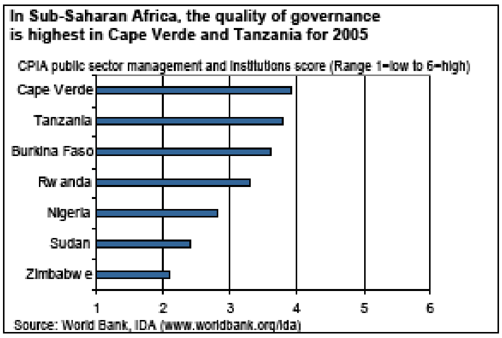


Fig. 1.9: World bank estimates of Governance levels in sub-Saharan Africa

As the case of **cellular telephones** has amply indicated, in fact many people in these developing countries are ready to (and usually do) pay higher for modern services and gadgets, than their counterparts in developed industrialised countries. For example, where a Tanzanian schoolteacher buys a cellphone for cash amounting to his/her monthly salary, his/her a German counterpart gets a better one on favourable credit terms renewed every two years.

1.3.8. The Solar nexus between “Tropical” and “Developing” countries

It is an observed (statistical) fact that most of the Developing Countries lie in the tropics, hence the term “Tropical Developing Countries”. From their tropical location, these **Tropical Developing Countries occupy a privileged position conducive for utilisation of direct Solar Energy**, due to the **special Solar Geometry** experienced there which gives them **high Insolation levels** almost all the year round, in comparison to temperate lands. Tropical countries experience about for 12 hour of daylight daily which in solar energy terms ranges between 4.5 and 7.0 peak sunshine hours (i.e. 4.5-7.0 kWh/m^2) per day. Because of this special advantage in terms of potential for Solar Energy utilisation they are, therefore, the best candidates for Solar Energy projects. In addition to this, due to economic and demographic factors characteristic of technological underdevelopment cited above, Solar Energy is for them currently one of the most promising options for short-term and long-term sustainable energy supply even in economic terms. The inadvertent direct advantage of technological underdevelopment is that there are no conformity limitations to new development due to previous developments observed in the more developed countries of Europe, America and Japan. For example, the fact of already having an extensive electricity supply network (Grid) of a given standard voltage (220V, 50 Hz AC for Europe and 110V 60 Hz for the US) limits manufacturers of equipment to energy suppliers to that voltage while in remote places without grid connections, different options (e.g. DC networks or different standard voltages) may be tried provided there is a technical or economic advantage in their use. Of the various possible forms of solar energy utilisation, Photovoltaics (PV) is of special interest, either alone or in combination with other electricity generation methods. Some countries of South Asia e.g. India, have noticed this geographical fact and taken advantage of it *(Shukla & Misra, 2002)*. According to *Aman et al (2004)* Bangladesh has also taken serious steps not far behind India.

1.3.9. The concept of “Government Services”

In comparison with their counterparts in developed countries, governments in most underdeveloped countries are less effective outside the capital cities, partly because of low or lack of technological infrastructure or lack of efficient application of technological resources in conducting their affairs. As stated earlier, the situation is much worse in sub-Saharan Africa. The modern sub-Saharan African state is a relatively recent creation as a result of colonialism. Although most countries in this world have experienced a form of colonialism in their histories, but that was long ago and have since had time to reorganise themselves and to build powerful state machineries directed by application of science and technology, first for military purposes but then later for general civilian applications as well. Quite unfortunately, however, Africa “missed the train” of technological development, partly as a result of recent colonialism and has so far failed to catch-up As background information to Government formation in Tanzania and Tropical developing countries, one may refer to *Tordoff (1967)* and to *Mawhood (1983)* respectively. *Stewart (1977)* has analysed the importance of Technology in development or underdevelopment of “developing” countries. One way of looking at a country’s technological development is by considering the degree of access of its people to its “**Government services”,** a term that combines both and public services as explained hereunder.

a) **State function**: Here we mean those activities which can only be performed by a “government” (central government, local government, or its department or executive agency). Usually these activities are in connection with the three “arms” of a classical “state”, namely the Executive, Legislative and Judiciary which enable it to “rule”. These functions usually, while remaining sensitive to the concept of “cost of operation” cannot or should not be associated with any concept of “profit making”. Such activities include public administration, diplomacy, defence, and “internal affairs” or “law and order” keeping (i.e. policing and related services), as well as legislation and justice administration. Among other things, smooth “state” function serves to create a good environment for it to “rule” and (where applicable) promote wellbeing and development of society and its activities as well as for the rendering of the public services to the society itself.

b) **Public Services**: These, are services that can be rendered either by a government itself or any other private organisation or agency for the benefit of general public, usually under government supervision and/or regulation. (By the term “private” we mean “non governmental in its structure”. Such entities can be commercial or non-commercial, secular or religious. By the term “**government supervision and/or regulation**”, we mean that the government in its administrative capacity sets only minimum “**standards of performance**” which other **service providers must meet** or exceed, and **sees to it that they are followed**). For private entities, in the rendering of such services, in addition to the concept of “cost”, “profit making” is also permitted depending on the “nature” or “constitution” of the service provider. Such services may include provision of healthcare, education, energy services and public communication, including public transport, public telecommunication and broadcasting and more recently “podcasting” and data communication services. The importance of public services is that under normal circumstances, they provide an economic base in terms of personnel resources and infrastructure through which a state obtains resources to run its function and provide for its citizens.

The degree of success with which the government of a given county discharges its stately function and directs delivery of essential public services to its people reflects its quality of **governance**. In sub-saharan Africa, this quality of governance is generally low, with most countries scoring below 50% (i.e. scoring less than 3 on a World Bank scale of 1-6). According to data from fact sheet of the *World Bank (2007)***,** already cited above, among African states, Cape Verde performs best followed by Tanzania (Fig. 1.7) However since overall score for each country is still below 4. This calls for some measures to improve the situation. It is therefore postulated in this work that provision technical resources, mainly electricity will help the governments in this task. As other factors do hinder extension of provision of grid electricity from conventional sources in all places, given the abundant insolation levels in these tropical countries, Solar Energy in form of Photovoltaic systems technology offers a way out.

In this research, therefore, we are dealing with state function in which photovoltaics may play a role either as a way of minimising costs or speeding up the provision of state services in question as well as some aspects of public services. We have shown the impact of utilisation of photovoltaics in the delivery of government services, both in **state function** such as judicial activities, security and village cohesion issues as well as some aspects of **public services** such as public water supply, information transmission and telecommunication services, especially in currently disadvantaged areas of tropical developing countries with Tanzania as the main test site. Special areas, namely healthcare, education and public administration have been singled out and given deeper attention. It has been shown that photovoltaics plays or has potential to play a big role either as a way of minimising costs or speeding up the provision of services in question in comparison to other situations where grid power is either completely not available, or so erratic that one usually delays in performing his/her power dependent activities or is bound to look for supplementary power sources usually at extra costs in addition to the ones already incurred in obtaining connection to the erratic power grid.

Disadvantaged areas include remote rural areas and some urban or periurban areas which are currently off-grid. Such areas are especially vulnerable and are, therefore, special candidates for this form of electric energy supply because due to their remoteness and low population density (in case of rural areas) or low production activity (in case of urban slums), extension of conventional grid services to these areas is not commercially viable. This is a special obstacle especially nowadays in the era of deregulation of energy services provision. Although provision of State function services is not supposed to be entangled with “profit making” it is a known fact that any State, especially a cash-strapped Third World State, should always be interested in providing its services in the most cost-effective way. That is why many Third World states including Tanzania usually provide their state functions better in urban centres with big enough population densities and economic activity levels and seemingly “neglect” the outlying rural areas and most urban slums. As a result, due to absence or inadequacy of such services, there tends to be a **“migration siphon”** that pulls more and more people from rural to urban areas thus exacerbating the situation in both rural and urban areas, contributing to poverty in rural areas through rural depopulation and poverty in urban areas through faster slum development. **Lack of adequate services and the struggle of individuals to benefit from the little there is breeds crime, corruption and other public vices** which in turn overburden the State in provision of its administrative and judicial services. This situation, in turn seems to demonstrate inadequacy of Government services including State function (legislation and regulatory functions) as well as Public Services in these areas. Installation of Photovoltaics (PV) in these disadvantaged areas, either alone or together with other energy resources in hybrid systems, provides a way of powering provision of the above mentioned Government Services more cost effectively than would be the case if the existing inadequate electric energy distribution grid were to be extended to reach all these areas, thus enabling governments to tackle questions of ignorance, poverty, disease, crime and corruption more effectively.

1.4. Objectives of the research for this thesis

In general terms, objectives of a research can be summarised by the following statement:

“Research aims to improve outcomes and services through providing evidence to inform policy, to direct practice and to develop products” which is a rephrasing of the opening statement on the website of the Aravind Research Centre[[5]]. This definition may seem narrow in general terms but in the context of this thesis is very interesting. With this in mind the objectives of this particular research can be summarised as follows as being to demonstrate the actual and potential role of PV application in, and its impact on government services provision in any tropical developing countries using Tanzania as a typical example. Such services are usually provided through activities and function through its various ministries and their respective lower instances or under their supervision. A related aim is to determine the role of the government in promoting PV in these applications. These particular objectives are further subdivided into the following:

- To help in the administration of government services, support and rule in tropical developing countries, using modern technology powered by electricity, of which photovoltaics, either alone or in combination with other energy sources, is a useful alternative.
- To determine and demonstrate the applicability of photovoltaic technology as a means of providing electric energy for government service delivery in currently non-electrified human settlements in tropical developing countries.
- To establish the conditions necessary for application of each type of PV installation of application and limitations to wide spread use of the technology will be examined.
- To determine what measures have been, are actually being, or can be taken by a government, in order to achieve widespread use of PV in its activities. These are the actual and potential role of the government.
- To make life easier for rural communities in tropical developing countries through easier access to PV powered government services which would otherwise not be available to them.

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[5] http://www.aravind.org/research2007/index.asp

- To enhance people's ability to use PV to run general life activities, obtain improved social and community services as well as conduct commercial activities.

1.5. Expected results (direct outcomes) and potential impacts of the research

This research project once done and successfully completed was expected to have a number of results and impacts divided into three major groups: Direct results or academic outcomes, indirect results or short term social outcomes around the research area and finally longer term impacts at a larger scale.

1.5.1. Formal Academic Results

These are, by definition, results that the researcher, (as well as supervisors and research authorities i.e. both Universities of origin and research venue), wanted to achieve by the end of the duration of the project. They may otherwise be called Formal academic outcomes of this research and are enumerated hereunder

- The main direct outcome of this research project will be information about the energy demand and the current state of photovoltaic technology application in government service provision in the countries under research, (in this case Tanzania and other countries for comparison).
- Proposals and recommendations for application of PV in government services provision will be put forward enumerating, among other things, the different roles of various actual and potential players, including various government ministries and agencies, donors and the private sector.
- Typical technical solutions for a decentralised electric energy supply for delivery of government services including building integration will be recommended. Hybrid systems with PV utilisation are developed for typical demand scenarios taking into account building integrated systems.
- The actual role of the government in promoting PV application for its own function has been analysed, some gaps have been identified proposals are put forward.
- Last but not least, suggestions for further research are also an item in the results list from this research.

1.5.2. Indirect results/outcomes (Social Capacity-Building Results)

These ones are those results that occur as a spin-off from the activity i.e. of there having been this particular research, though they might not have been the main aim of the research as originally intended.

- The information generated during the research, will contribute towards a greater understanding of the actual and potential impact of utilization of PV and other RETs in Government services provision activities in tropical developing countries in general, Su-Saharan Africa, the East African sub-region and Tanzania in particular.
- This work will stimulate further action of incorporation of PV and other RETs in Government service provision as well as in daily life activities by various members of society and other stakeholders.
- Utilization of Information and Communication Technology (ICT) will make a quantum leap into remote areas, where without PV power supply would be a bottleneck to ICT development.
- Based on findings of this research more research in this field will be made possible.

1.5.3. Impacts of this research

- **Government decision makers** will find this thesis an authentic source of information on which to base their decisions when it comes to selection of energy sources for their activities.
- The results of this research will contribute towards improvement of provision of **Government services** such as **education, healthcare** and **public administration.** Workers in the **judicial services** and **law enforcement** also stand to benefit through enhanced use PV-powered ICT and the possibility of extended their working time beyond sunset with PV powered lighting, especially in rural areas as well as in many urban and semi-urban centres in third world countries that are currently not adequately electrified. The resultant speed of implementation of activities will contribute towards further reduction of temptation for corrupt practices.
- This thesis will serve as aid for quantifying electricity demand for typical public facilities, dimensioning of technical plant and calculation of the necessary energy budget.
- The impact of electrification of government services provision through PV (both stand-alone and in hybrid systems) on **government function** especially in rural areas, which was so far not so well-known, has been highlighted in this thesis. PV serves as a safe and sustainable energy supply for such areas.
- This thesis will serve as a source of practical details for development of **building integrated** (BIPV), for tropical countries. Although **free standing PV** remains an option of in PV deployment, from this author's experience this option is associated with many security problems in Africa. It is, therefore, not dealt with in this thesis.
- Depending on power demand and its pattern at a particular location, PV may be used either alone (**stand alone PV systems**) or in combination with other energy resources (**hybrid PV systems**).

Needless to say policing work will be greatly improved if all outlying police stations and police posts could be powered through PV. All **police communication and record keeping** will be greatly improved. **Boarder posts**, such as Horohoro, Namanga, Sirari, Mutukula, Tunduma and Kasumulu, just to mention a few in the case of Tanzania, are all in remote places and usually manned by a few personnel and their families living there. Power supply to such remote places, by grid extension or using or small generators running on fossil fuels is usually expensive and often not done except in very special circumstances. Electric energy supply to such important government posts through PV may help in combating all cross-boarder illegal activities such as drugs and arms trafficking thereby rendering more credibility to the notion of "government presence" in such remote places.

The effect of PV on **defence** efficiency cannot be overemphasised. PV will be used in powering all military communication especially in field conditions. **Disaster** response or appropriate action or other fast moving conditions where quick set-up of operations is required can be greatly and affordably enhanced by quick installation of PV systems in areas where fuel delivery for operation of conventional generating sets would be problematic. Use of PV, frees some valuable capacity in the supply chain where fuels and other heavy power generators may be brought to site at a later time (or not at all), after initial deployment of PV facilities, thereby improving on **effective reaction time**.

The impact of PV on **education** is that, **students** and **teachers** especially in **home environments after school** will have more study or preparation time using PV lighting. In addition PV powered ICT will improve educational material sourcing. As a result they will be able to gain or to impart more knowledge that will empower the learners to better cope with their difficult life in developing countries. At school, especially the newly developing **rural secondary schools** in Tanzania, for example, PV application enables set-up and use of modern teaching/learning facilities, such as computers, beamers, projectors, and multimedia as well as experimental gadgets for science instruction. Without electricity, it would not be possible to use such facilities. In addition, remote study (officially known as **"Distant Learning"**) will also be made possible through PV powered ICT tools such as computer networks and the Internet in places where they would have otherwise been difficult if not impossible to find and/or to use.

In **boarding schools**, a move from kerosene lamps to PV lamps for night lighting will contribute towards reduction of fire hazards usually associated with petroleum burning appliances especially kerosene lamps. A quite sad case example in this aspect, is the burning to death of about 40 teenage schoolgirls at Shauritanga Secondary School in Moshi Rural District of Tanzania, as a result of a dormitory in which they were sleeping catching fire from a kerosene lamp used for night illumination there.

Fig. 1.10: A move from traditional kerosene lamps used in Tanzania

Fig. 1.11: Towards a better and affordable PV powered lighting alternatives

This move from kerosene to PV lighting, will also reduce carbon emissions from the kerosene lamps, which although seem small per lamp, but when the number of lamps in use throughout the region is considered, then the carbon emissions reduction is considerable. In fact, this move can generate positive monetary gains from carbon trading according to the **Kyoto protocol** if one cares to apply to appropriate **"Carbon Markets".**

The use of PV in delivery of **medical services** in rural areas is well documented, especially the **cold chain** system necessary in many mass **immunisation** programs. For the moment, at least, it is aspects of **telemedicine** that still have a lot of ground to cover. In this regard, new possibilities are being provided by affordable PV powered ICT application in medical technology. A case on PV powered telemedicine in South America is reported by *Martinez et al (2004).* Although many reported studies on this issue are about Latin America and the Caribbean *(Rodriguez at al (1998)***,** the information is still valid and can be useful as reference for similar projects in Tropical Africa. In proposing such activities one has to contend with resistance not only from the "ignorant and illiterate" local populations but also from some "qualified" professionals and officials of all kinds who need some sensitization and demonstration of innovative approaches and new technologies. Dr. Hellen Einterez, for example, who says she has worked in remote areas in North Cameroon, in one of her submissions to the Canadian Medical Association Journal (CMAJ), lists a litany of problems that she thinks must be solved first before one may even think of telemedicine for Africa. However, she fails to see, the opportunities by PV in powering not only telemedicine, but also the water supply and education problems that are at the root of the problems she is presenting as obstacles. [[6]]

As for the general public, the ability of people to use PV and, therefore, a move away from fossil fuels for lighting, especially in rural areas (as well as in unelectrified urban and semi-urban centres) will have a profound impact on their life. For example, it would save the people from bad health due to inhalation of kerosene fumes. Needless to repeat is the carbon saving which will occur as a result of a dramatic switch from small kerosene fuelled lamps to PV lamps is considerable when looked at, at national and continental scales. The impact of PV powered ICT facilities on rural public life, from running of simple cell-phones based telecommunications services, (phones themselves and their transmission antennae towers), through Radio and TV broadcast reception to rural Internet Cafes cannot be overemphasised.

In conclusion, this research, therefore, encourages electrification and speed-up of public administration services and judicial systems especially in relation to remote areas in tropical developing countries the world over. All low power applications such as lighting, Information and communication technology (ICT), domestic and medical refrigeration, diagnostics and administration as well as some aspects of education, stand to benefit through PV utilisation.

1.6. Research methodology

- Examination of documents in various libraries and on line has been quite helpful. Many papers, books, web-pages and other electronic documents are shown throughout the text and their details are then summarised in appropriate appendices at the end of this thesis
- Selection of a single Tropical Developing Country to be used as a typical example. In this case Tanzania was selected because it was best known to the author, was more easily accessible and data could be best accessed by the author.
- Review of a Government set up, using the Tanzanian Government as a typical example, with intention to establish two important points:
    - What role can PV play in facilitating the daily activities of each government ministry in rendering its services to the people it serve?
    - What measures can be taken by particular government ministries to enhance greater utilisation of PV in the country?
- This task has been accomplished by examination and further analysis of available published statistical and other data, mainly from Tanzania, but in some cases some examples have been taken from outside Tanzania as well.
- Case studies: Personal study of some cases in and outside Tanzania in which PV has been/is being used to renders services similar to the expected government services.
- Site visits and attendance of exhibitions and conferences has proved to be a valuable source of both academic and industrial information that has been utilised in this thesis.
- Calculation of energy demand in a few sample typical service facilities (e.g. school Hospital and Public administration buildings) and redesign of the same incorporating PV has been carried out.
- Development of implementation strategies on distributed local or national level, including financing models.

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[6] http://www.cmaj.ca/cgi/content/full/165/6/780

Summary of Chapter 2: Theoretical Discourse: Presentation of theoretical background to solar energy, especially PV and its applications, especially in buildings. Specificities of solar energy and PV for East Africa are also presented. A few examples of PV installations currently in use by some private organisations and individuals in Tanzania are given.

2. STATE OF THE ART and LITERATURE REVIEW

2.1. The Energy question in Tropical Developing Countries

The living pattern of the people in these rural areas of developing countries is usually dispersed. People live in small dispersed clusters called villages, with **low present day electric energy demand**, low levels of energy and communication infrastructure both in bulk and density, low industrialisation levels etc. This situation is well described by *Koenigsberger et al. (1973),* in the foreword of their **"Manual of Tropical Building. Part 1, Climatic Design".** From the point of view of an investor in traditional conventional **Centralised Electric Energy Generation,** the above named situation in rural areas of tropical developing countries puts them in a difficult economic position as no sensible capitalist/investor, driven by **returns on investment**, would put their money in energy provision to such people and regions. On the other hand, from the **Distributed Electric Energy Generation** point of view, this situation offers to these tropical countries, a unique economic position for **utilisation of Solar Energy** and **other Renewable Energy resources** (most f which are also indirect variants of the same Solar Energy). At the current level of technological development, Renewable Energy resources may offer advantageous, **financially viable and competitive** options for particular purposes. This is in addition to fact that Renewable Energy Resources are always basically Environment- friendly. This point of view was also presented by a famous German Environmental activist and Federal Parliamentarian **Herman Scheer** in his interview with **Burja Kalenka**. The complete text of this interview is annexed to this document. A recent **World Bank** study also seems to share this opinion ***(World Bank 2000)***.

2.2. The importance of Electricity to Developing countries

(Electricity - the key energy resource for technical development)

There are many forms of energy in use, of which Electricity is just but one and Photovoltaics (PV) is just one among many various methods of its generation. It is a well known scientific fact that all forms of energy are interconvertible, therefore, from the scientific point of view it does not matter which form of energy one starts with; given the right gadgets, one will always arrive at the right form of energy, necessary for particular applications. However, from the technical-economic point of view, some forms of energy are more suitable as starting points for particular applications than others. Of these, Electricity as a starting form of energy (or input form) is of particular importance. Due to its versatility, ease of conversion and convenience in use, Electricity has become a universally accepted basic starting form of energy, to the measure that it can be used as a measure of technical development of a society.

A society will be judged to be more or less developed by referring to its degree of electricity use, both in bulk or per capita. **The higher the degree of electricity uses, the higher the degree of technical development** of an individual, nation, society, or place. It can, therefore, be stated here that **use of electricity is synonymous with technical development**. From this statement, it follows therefore that, in order to have meaningful technical development, for the so called developing countries, it is imperative for them to be able to generate and use more electricity both in bulk and per capita than they are currently using. The only problem is how best and most sustainably to achieve this goal. This issue must be a subject of more and more research as time passes and more and more people are concerned by the degree of technical backwardness of Developing Countries, especially those in Africa, including Tanzania. Given the tropical location of most developing countries, especially those in Africa, Photovoltaics seem to offer a reasonable solution for generation of electricity in amounts critical to the people's technological development.

2.3. Electricity Generation and use options for Developing Countries

There are many conditions in which Electricity can be generated and utilised. The **Choice** of a **Method of Electric Energy Generation** (including PV) and/or its **utilisation** is usually governed by many **factors and considerations**, such as **Resource Availability** and **Technical Feasibility** factors as well as **Environmental, Economic, Financial, Business, Social** and **Political considerations**. When we speak of Energy Applications (including Solar and PV), we usually mean its utilisation by people in their day-to-day life activities most of whom, nowadays, live and work in and around **the built environment**. As such, this work deals with Electric energy generation and its use in the built environment. Here we are speaking of stationary objects as opposed to those in motion. Developing countries being not industrialised, their energy use in the built environment is limited. As we shall see later, of this low energy demand, **specifically electric energy demand** is even lower because the most energy-demanding activity is heat making for domestic activities and this can be more economically performed using other resources, such as biomass. The fact that most people in Developing Countries live in small separate houses in rural areas further adds **dispersion** to this **low electric energy demand**, further complicating the picture. In case of centralised generation, this would result in higher operating costs per unit of energy delivered, compared to a developed country situation where more electricity is demanded per capita and people live more compact in multi-storey buildings in big cities. In Developing countries, electricity is used there or in such gadgets, where its use as primary energy input is of particular importance or significance, for example in appliances designed to accept only electric energy input, such as modern electronic telecommunication gadgets, or where electricity offers particular advantages such as in electric lighting. Both these above mentioned activities are low power application, once again indicating their suitability for use with **low power dispersed electric energy generation**, which further suggests Photovoltaics (PV).

Photovoltaics (PV), as a form of input energy resource, is rarely employed alone. Normally, in a typical housing situation, there are many different activities which require different input energy forms which in turn require different energy resources for their operation at the most efficient. It is also a well known fact that although all energy forms are technically interconvertible, energy resources may be graded on a **scale of value levels**, from Primary energy resources to higher levels, based on their **natural availability** and the **economics** of their utilisation. **.** So, as a result of this interdependence and gradeability of energy resources, this study , in addition to all the above mentioned factors and considerations, also looks at the **Architecture** of the built environment in which this energy is used as well as the **other electrical and non-electrical alternatives** which may complement, help, compete with or hinder application of PV.

Energy efficiency, for example, will reduce the **demand** and therefore the **size** and in turn the **capital and running costs** of any energy system that will be installed for utilisation in given building or settlement. Good building **insulation** or **shading** will definitely affect the building's

energy bill for heating or cooling, thus making a limited energy system resource cater for more applications in a given dwelling unit or take care of more residential/working units in a given settlement. Moreover, different energy resource systems working in tandem, may together work more efficiently than any single resource alone. This, for example, is the case in cogeneration, using conventional resources. The same principle also applies with renewable energy. A given settlement, for example, may be more economically operated by a **combination of PV** and Wind, a biodiesel power plant and one or more Storage Battery Set(s) in a **Hybrid Installation** rather than only one of the above mentioned items alone. Furthermore, collection, storage and appropriate utilisation of **Rainwater**, in the above mentioned settlement may further add to the economics of the installed **Hybrid Energy System**, in that less energy will be expended on water supply. Last but not least, introduction of a **Biogas** powered unit into the Hybrid Electric Energy System, may further enhance the economics of Electricity. Otherwise, Biogas may reduce the electric energy demand, especially for heating purposes, thus further liberating the installed capacity of hybrid power unit for other purposes. Biogas may also be incorporated into the Electric Energy Hybrid Complex by using it to run a conventional generating set using an internal combustion engine, where biogas either alone or in mixture with natural gas may power the engine. Biogas as a source of hydrogen may also be used to feed a **Fuel Cell** Electric generating unit. Other hydrogen sources for running fuel cells include direct electrolysis of water and catalytic cracking of hydrocarbons. However, at their current level of development, Fuel Cells cannot yet be economically employed for electricity generation especially given the price of other available alternatives. However Fuel Cells may be used for scientific and further development purposes. Biogas is obtained through proper management of Solid and liquid waste especially in areas with high human and animal population concentrations, such as Big farms, Schools, Hospitals, Missionary and Administrative Centres. A more modern State of the Art general picture of Renewable energy is summarised by *Aitken (2003).*

As said above, there are many possible uses of PV either alone or in combination with other electrical or non electrical energy resources. However, together with other factors, the size of the PV installation has a special significance in the type of PV application. Thus, PV installations are classified according to size.

This classification is summarised by the International Energy Association (IEA) Task 9 report. *(IEA PVPS T9-01:2002).*

2.4. The concept of Photovoltaics

As stated before, **Photovoltaics (PV)** is a science/technology of **transforming incident Solar Radiation <u>directly</u> into Electricity**. This is usually done in Photovoltaic Cells which are, basically, solid-state semiconductor devices that that emit electrons upon being shone upon by electromagnetic radiation of a given frequency (or wavelength) range which reaches the cell location.

In outer space, all the solar radiation spectrum as emitted by the sun is available for conversion, whereas on earth, however, the solar radiation is modified after passing through the thick layer of the atmosphere, where some frequencies (wavelengths bands) are absorbed by various atmospheric components. In addition, some of the solar energy is reflected back and/or scattered. As a result, solar energy reaches the earth’s surface a combination of direct and diffuse radiation. Whose intensity varies according to the location on earth, time of year and exact atmospheric conditions prevailing over the location in question. There are many scientific documents dealing with this theme.

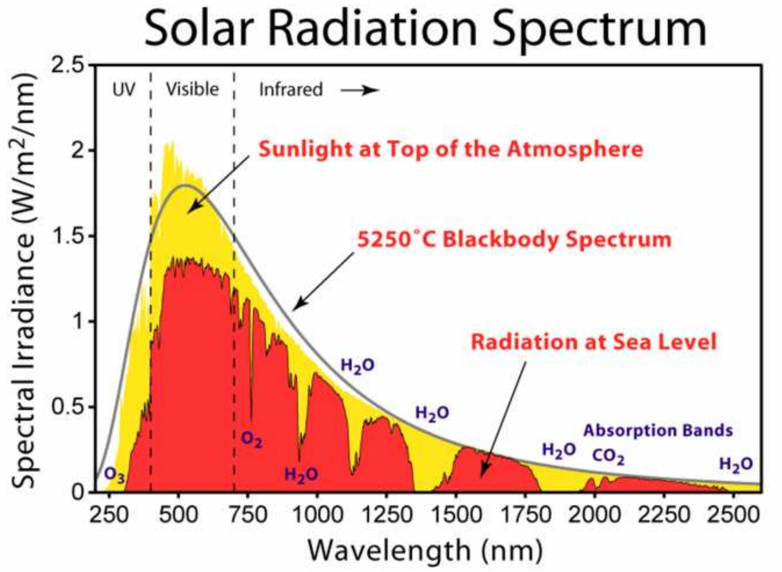

Fig. 2.1: The effect of the atmosphere on the solar radiation spectrum reaching the earth[7] [4]

The cells we are mainly concerned with here are sensitive to electromagnetic radiation within the visible part of the Solar Radiation Spectrum which we usually call "Light". The Physics of Photo-electric emission is dealt with in many treatises including, (but not limited to) *Kazimierski (1997)*. Depending on the material used and method of fabrication, we now can distinguish between **Crystalline (Monocrystalline** and **Polycrystalline), Amorphous Silicon** and other **Thin Film** cells e.g. Copper Indiun di Selenide (CIS) and now the second generation thin film technology called **Crystalline Silicon on Glass (CSG)**. Thin film photocells have the advantage of using less material in the cells themselves and wasting less material during their production thereby providing cheaper options for generating PV electricity. At present CSG technology is the most promising of all thin film technologies. With this technology **a thin film of polycrystalline silicon** is deposited on a large glass sheet in various layers, then the sheet is subdivided into cells. The resulting photocells have the advantages of both polycrystalline and thin film technologies, i.e. combining relatively higher polycrystalline efficiency and lower thin film production costs *(Basore 2002)*.

They seem to have a lower conversion efficiency in terms of surface area but they compensate for this in terms of lower unit production costs in power terms (€/Wp or $/Wp) due to lower material consumption and from the fact that sunshine is obtained free of charge (i.e. has no input cost). However this effect can be felt when for any other reason, physical space area is limited.

The combination of **light concentration** and **thin film triple junction cells** has recently made history in terms of Solar energy conversion efficiency (exceeding 40%), according to *Justin Thomas (2007)*.[8] **[5]**

The Electrical power (voltage and current, generated by a single Photocell (PV Cell) is too small for many practical application. So for these purposes, PV cells are usually assembled in series to form chains that are also arranged in parallel to form **Modules**. Modules are usually the basic utilisable units in Solar Electricity generation, which would be dealt with by Architects and Engineers. They are also classified according to the type of PV cells of which they are made, into **Mono-** and **Poly-crystalline**, as well as **Amorphous Modules**. Although **Thin Film** modules are just a recent introduction and the name is not so current, people prefer speaking about **Sheets, Rolls** etc, because the technology allows deposition of the Photo-active material in a thin layer on flexible materials and curved or even irregular surfaces of unlimited dimensions and

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[7] http://www.globalwarmingart.com/index.php?title=Image:Solar_Spectrum.png&printable=yes

[8] http://www.treehugger.com/files/2007/04/stateoftheart_m.php

shapes. With the development of the new second generation thin film technology, the **Crystalline Silicon on Glass (CSG)** technology, **CGS Modules** are now already in production. CGS technology, developed at the Center of Excellence for Advanced Silicon Photovoltaics and Photonics of the University of New South Wales (UNSW) in Australia, *Basore (2003), Green et al (2004)*, has since 2006 taken industrial footing in Germany *(Basore 2006 a, b)***,** where the first industrial production plant has started, in order to take advantage of the conducive market development atmosphere (in terms of governmental political will, legislation and economic measures taken) now prevailing in Germany and promising to spread all over Europe. In the meantime more research is going on and as as reported by *Basore (2005)* the CGS modules are constantly being improved and optimised through continued R&D. More information on CGS can be found on-line at.[9] [6]

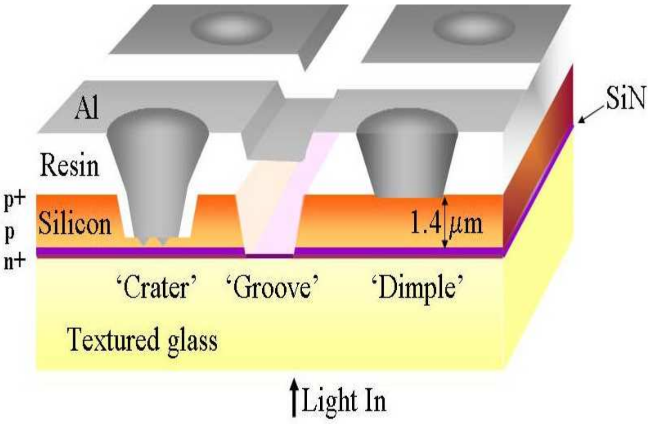

Fig. 2.2: Section through the CIGS thin film (showing the manufacture principle) *(Basore 2005)*

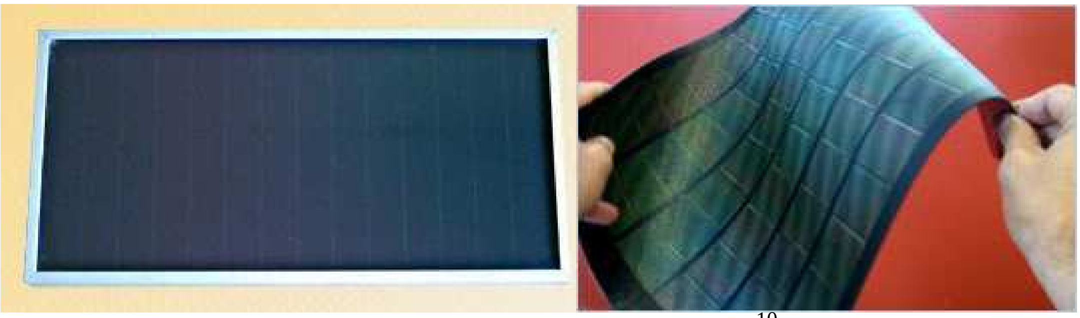

Fig. 2.3: Rigid and flexible CIGS thin film PV modules[10] [7]

In addition to bringing closer the possibility of cheap (affordable PV), CIGS technology provides possibility powering small portable ICT gadgets such as cellphones and portable computers thus enabling cheaper application of these technologies in various situations such as providing power for work in emergency situations, field studies, policing and of-course, coordination of military field operations.

Other promising PV cell types, in terms of efficiency and production costs are in various stages of development. Such cells include the **dye sensitized cells** such as the **Graetzel Cell** that mimic the natural photosynthesis process. A very promising recent breakthrough in the development of such biomimetric dye sensitized cells is the one recently developed by Annemarie Hujser at the TU Delft, Netherlands. A comprehensive description the principle and the process is to be found in her recent PhD Thesis. *(Hujser 2008)*

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[9] www.csgsolar.com

[10] www.rewarestore.com/tech_thinfilm.html and www.rewarestore.com/reducation.html

Other developments in the thin film cell preparation techniques include application of the time-tested **inkjet printing** technologies to deposit photosensitive materials on different substrates. This same method can be used not only in preparation of printed thin film PV cells but also in the manufacture of very thin batteries for portable gadgets (a very important BOS item for PV) and other responsive materials such as “smart” tags and smart packaging for goods tracking in logistics, smart cards, smart uniforms for soldiers and students and many more applications. These are also related to PV as Balance of System (BOS) appliances detectable using PV powered portable or fixed gadgets. In general, inkjet printing technique, using well-known and standard inkjet printers, is a very promising step in thin film deposition technology for use in manufacturing of various types of thin film PV cells and modules.

PV Modules can be further integrated into **arrays** of different physical sizes, and electrical parameters according to requirement. Depending on their **location** as well as **intended operation** and **local solar energy availability characteristics**, PV modules may be **fixed** in different planes, such as **horizontal, inclined** or **vertical**, and when not fixed, PV modules or arrays may be made to follow the sun (**tracking)** about **one axis** or about **two axes, (**usually daily, from east to west or in addition, seasonally in the north south direction). The tracking PV installation have the advantage of being able to provide more energy over a given period of time for a given module/array size in comparison with similar fixed installations, but have the disadvantage of being more expensive in installation and maintenance costs, because of having extra and movable parts. On the other hand, **fixed PV** installations have the advantage of being able to play other roles in addition to energy generation. For example, they provide for possibility of incorporation into building surfaces such as roofs and facades, where they may play these “other roles in addition to energy generation”. This is called **Building Integrated Photovoltaics (BIPV)**. PV modules applied in this way, may work as a **roofing material**, thereby replacing conventional roofing fully or partially over the roof part on which it is placed. They may also play **solar shading** roles when incorporated in roofs and windows or may simply work as **decorative** cladding on walls especially in northerly and southerly latitudes where solar angles permit vertical or quasi-vertical installation of such elements without sizeable loss in electricity generation capacity of such elements. Nowadays, solar cells and their modules may be made in many colours and shapes thereby giving architects and builders the opportunity to be creative in their application, not only in relation to amounts of energy they generate but in building aesthetics as well.

2.5. The Balance of System (BOS) of a PV system and its Components

(Charge controllers, Batteries, Invertors, connecting wires and Loads)

The PV modules serve only one function, that is transformation of sunlight, solar energy into electricity. However, for proper function of the PV system, the rest of the components must also be in proper and efficient working order. They must also be matched for working together.

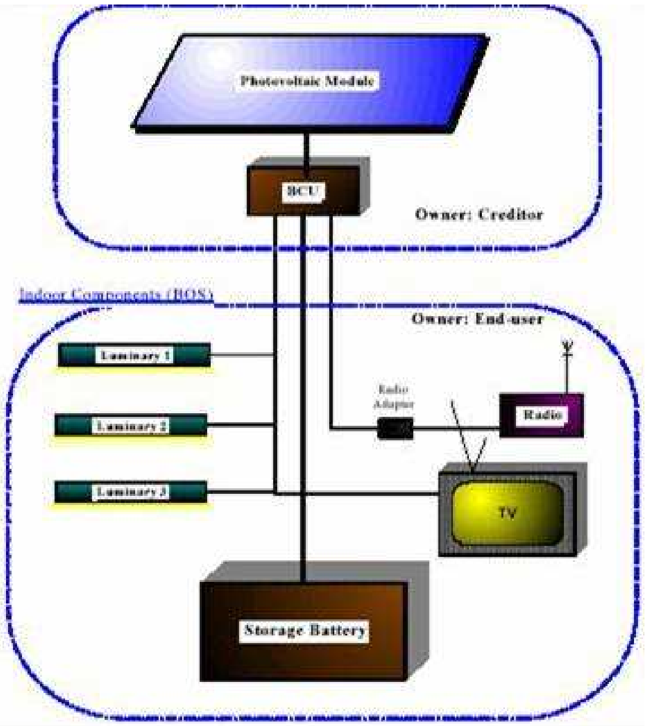

Fig. 2.4: A typical stand alone PV solar home system (SHS) and its major components

2.6. PV systems and their application niches

Once electricity is generated from the PV modules, it is then to be either immediately used or stored waiting for the appropriate time and demand. This is usually accomplished through the use of batteries, the most common of which, for big stationary applications like school lighting systems, are currently lead-acid batteries. Electric energy storage in batteries can be made in many voltage configurations, but for safety reasons, the most widely used in small stand alone PV systems are 12V or 24V DC systems. Since standard lead acid storage batteries are usually made as 12V DC packs, for a given storage capacity, and fixed lead distances (and, therefore, wire lengths) from module to battery bank a 24 V system requires twice the number of batteries than 12V system but half the lead wire thickness because of lower currents. So a 12 V system has the advantage of lower battery numbers and the disadvantage of thicker wires (or else higher Ohmic losses). However, with the aim of keeping costs down, since batteries are usually more expensive than wires, in small compact DC systems, a 12V system is to be preferred over a 24 V system. On the other hand, for bigger system over an extended large area, in order to avoid energy line losses and to be able to use the are relatively cheaper standard off-the-shelf appliances, the load circuit from the battery to the appliances is best configured as an AC system, through an inverter and a local mini- or micro-grid.

In many applications, electric energy demand does not always coincide with supply in space and time (from solar radiation whose intensity predictability is limited). Therefore, in order to have a PV installation properly functioning to user satisfaction, an energy storage and control mechanism is usually required. Due to a number of reasons, most common “off-the-shelf” electric appliances are made for use with alternating current (AC), while PV usually gives direct current (DC) either directly from the modules/arrays or from storage batteries. As a result of this discrepancy, most PV installation that use standard off-the-shelf appliances do incorporate one or several DC-AC transformation devices (called **inverters**) that convert the available DC to the required AC. In view of the difficulty of **constant matching** of load to generated energy in PV systems, (due to erratic nature of natural energy streams including solar radiation), it is not always good enough to use PV only **(stand-alone PV)** for electric energy generation in critical situations, unless one has enough electric energy storage capacity. In some cases PV may be used in combination with other electric energy generation methods. This is called **hybrid PV**

systems. In many developed countries PV generated electricity is usually supplied to the existing electrical grid system. This is called **grid intertied or interconnected Photovoltaics (GIPV)**. This latter option has the advantage of eliminating the need for local energy storage and its associated costs, but requires reliable electric grid function because for safety reasons PV electricity is not allowed on a powerless grid. Some commercial arrangements that encourage such application of PV are also made, in which the price of PV electricity to the utility is higher than the price of an equivalent amout of grid electricity to the user. Quite unfortunately, at least for the moment, GIPV cannot be used in most Third World situations because of the unreliability of grid supply itself. Currently there is only the possibility of **PV being used alone or in combination** with other renewable energy systems or fossil fuel based portable small scale generators on a **local minigrid** or **microgrid**.

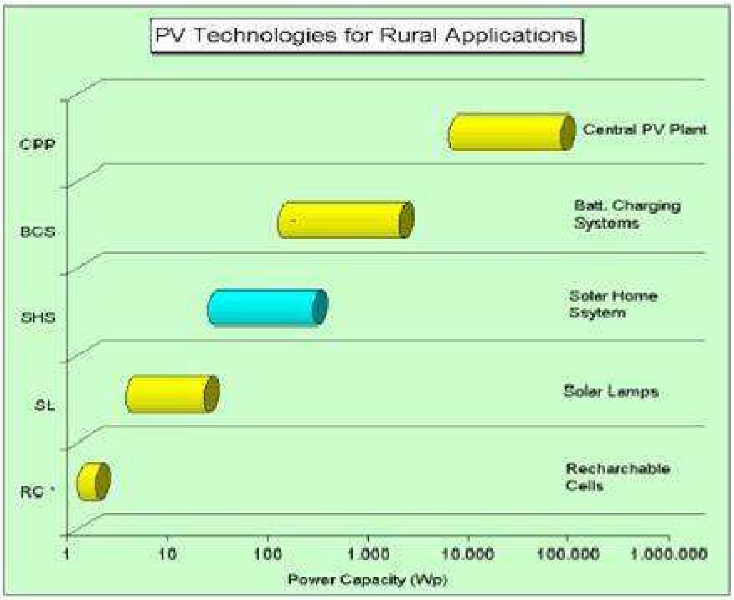

Fig. 2.5: Typical PV application ranges according to their installed power

As a result of the foregoing, a complete and comprehensive study of PV and its application must also consider **Modification, Transmission** and **Storage of Electricity** in addition to its **Generation** and **Utilisation.**

The **choice** of PV and/or any other method of electric energy generation and/or utilisation is usually governed by many factors and considerations, such as **Resource Availability** and **Technical Feasibility** factors as well as **Environmental, Economic, Financial, Business, Social and Political considerations**. When we speak of energy applications (including Solar and PV), we usually mean its utilisation by people in their day-to-day life activities. Generally, nowadays most people live and work in and around the built environment. Government Services of which this study is about are also conducted mainly in buildings. So this study also looks at the Architecture of the built environment mainly government buildings, in which this energy is used as well as the other non-electrical systems that may help, compete with or hinder application of PV in Government Services. As presented before, in a PV dependent electricity supply system, whether hybrid, or stand-alone, the PV modules may either be designed to be part of a building or independent of it. In the provision of PV for Government Services, it is therefore, possible to design buildings in which Government Services are being rendered to incorporate PV modules and thereby linking **Architecture, PV technology and Government services provision**. This study about **“Utilisation of PV in Government Services Provision in Tropical Developing Countries”,** therefore, deals with the three above named fields.

2.7. Energy storage in PV installations

Since PV systems operate under solar radiation, the duration and intensity of which are modified by weather conditions over which man has no influence, it is necessary to either constantly (dynamically) match operating loads to available energy, or find a way of energy storage for use on demand irrespective of the solar conditions prevailing at the moment. Since dynamic load matching is difficult various forms of energy storage must be employed in any systems involving PV and indeed, many renewable energy based systems.

In general terms, energy storage can be conducted in many ways, such as:

- Mechanical storage:
    - Gravity (mass level change) (liquids)
    - Compression (air/gases)
    - Elasticity Deformations (solids springs)
    - Flywheels (mechanical energy stored in form of rotating mass)
- Thermal:
    - Phase change (based on latent heat of fusion/vaporisation of active materials)
    - Thermal mass (based on specific heat capacities of heat storage materials)
- Electrical storage:
    - Utility grid feedback (based on sales to grid and buy back of electricity from grid)
    - Electric field, (through capacitors and ultracapacitors)
      (a new addition in ultra capacitor technology is the recently announced one atom thick graphene ulta capacitor[11] [8]
- Electromagnetic storage:
    - Magnetic field/resonance
- Electrochemical storage and conversion devices.
    - Batteries
    - Fuel cells
- Chemical storage in form of:
    - Fuels:
        - Natural fuel for combustion
- Biomass based fuels
    - Simple dry solid biomass (firewood, animal dung, agricultural plant residues)
    - Simple physically processed biomass (wood pellets, charcoal, charcoal pellets)
    - Products from processed biomass (Biogas, liquids bioethanol, biodiesel)
- Fossil fuels (a result of ancient solar energy storage, eg. Petroleum products & natural gas)
    - Hydrogen for direct combustion in internal combustion engines
    - Hydrogen for fuel cells
    - Charged electrolytes for use in flow batteries, e.g. the Vanadium Redox Battery (VRB)

Of all these energy storage systems, the most important in PV industry are Utility grid feedback and various types of battery storage systems. Among mechanical storage systems, the most promising is Flywheel storage system, but it is still under development. Of course, water storage and compressed air systems could be powered by PV, but the stored energy is best utilised directly in the form of the stored material eg water or (compressed) air but reconversion to electricity would not be economical. However, while grid feedback systems are typical and standard in industrially developed countries, use of battery based storage systems is the norm in tropical developing countries including Tanzania and the whole East African region even in cases of existence of local mini and microgrid based hybrid systems that include PV. For this reason more discussion will deal with battery based storage systems either in stand-alone or hybrid PV sys-

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[11] http://www.sciencedaily.com/releases/2008/09/080916143910.htm

tems (i.e. where another energy source is used in addition to PV). There are many types of hybrid PV systems, but currently the most interesting PV hybrid systems are PV-Biofuel systems which use PV in conjunction a conventional generating set running on a form of biofuel from locally grown plants, mainly Bioethanol from the local sugar and sisal industries or Jatropha oil from locally grown *Jatropha curcas* plant. More discussion on biofuels and especially Jatropha is coming in subsequent divisions of this thesis.

2.8. Batteries as special energy storage systems

Batteries are chemical sets that have a potential difference across their terminals and give out a current when the terminals are connected to a load. The simplest battery units with given typical electrical parametrs are called cells which can be designed and manufactured for single use (primary cells) or multiple uses through charge-discharge cycles (secondary cells). Cells can be combined in different ways to give specified standardised operating criteria such as voltage, current and capacity. These cell packs are called batteries and can similarly be for one time use (use-and-throw-away) or reusable (charge-discharge) gadgets depending on the type of cells of which they are made (i.e. primary cells for non rechargeable types or secondary cells rechargeable types). The rechargeable batteries are also called accumulators, in order to distinguish them from their non-rechargeable cousins, but usually the term “battery” is often used for both. These are charged using an already existing source of electricity and so they are very suitable for use in PV systems because they give back power in electrical form immediately upon connection into a circuit.

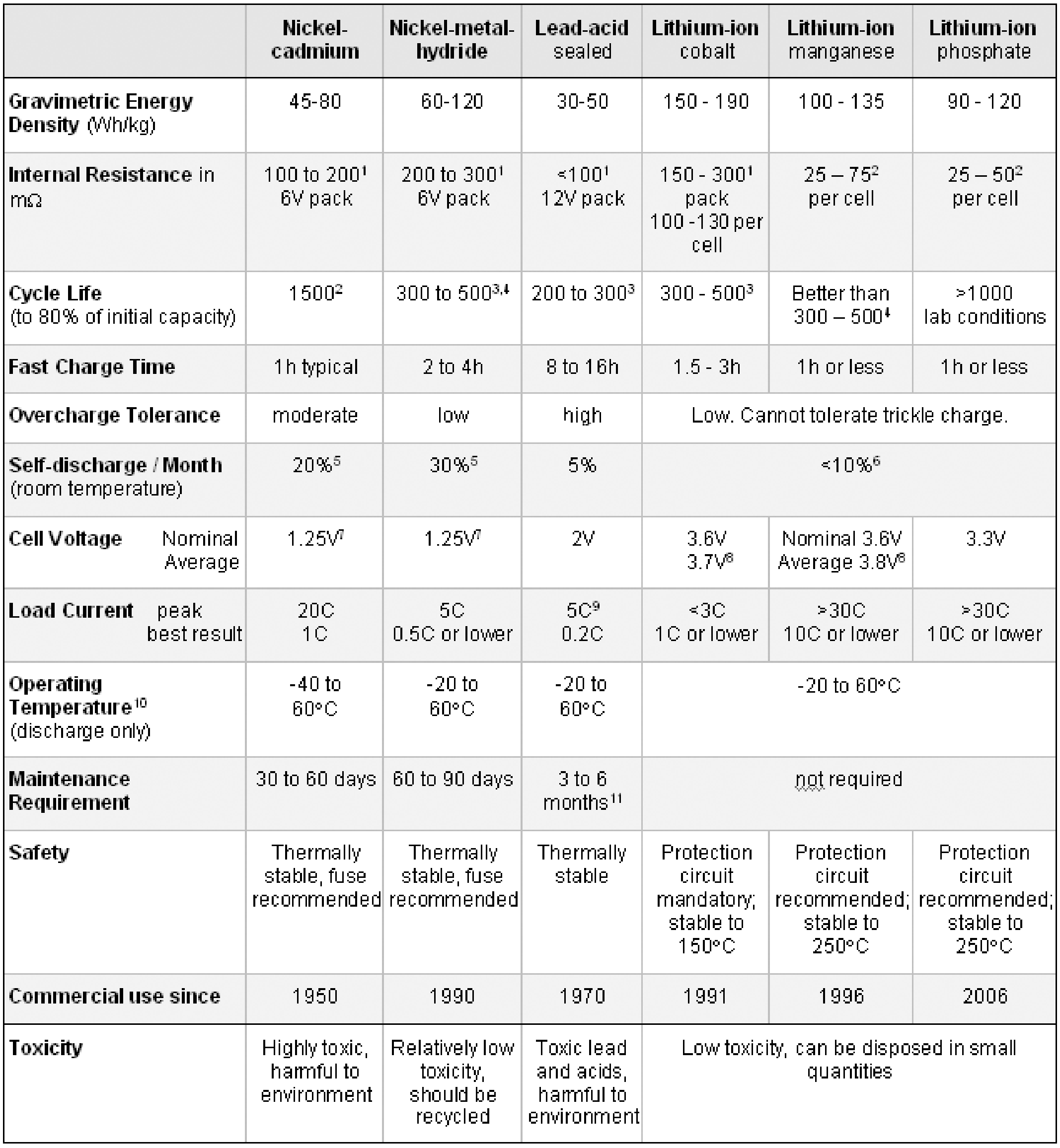
For our purposes of PV electricity storage, accumulators are the most interesting. Therefore later discussion will concentrate on them. There are many accumulator technologies and corresponding types suitable for various uses. The choice of a battery storage system depends on the following factors:

- The operative requirements of the user
- Technical sophistication of intended equipment operators
- Availability and technical sophistication maintenance personnel
- Range and technical parameters of available loads (energy consumers) or appliances such as:
    - The physical size of the equipment to be powered
    - The power requirements of the equipment to be powered
    - The energy consumption pattern of the use or gadget in question (e.g. when, how long and how frequent that appliance is switched on and off)
    - The specific working conditions and environment of the powered appliance. (e.g. Whether the appliance is stationary or mobile, or the temperature of its operating environment, etc.)
- Range of technical parameters of available storage devices
    - energy content and energy density /densities
    - durability /longevity in absolute time or number of charge/discharge cycles
    - size, bulk weight
    - Run time between two consecutive charges
    - Cost
    - Reliability

    - Other maintenance requirements (e.g. cleaning, topping-up etc)
- Financial resources and services available and accessible to intended users and operators

The most common types of energy storage batteries, their evaluation parameters and their uses are as summarised below by *Buchmann (2005).*[12] **[9]**

Table 2.1: Characteristics of commonly used rechargeable batteries *(Buchmann (2005)*



	Nickel-cadmium	**Nickel-metal-hydride**	**Lead-acid** sealed	**Lithium-ion** cobalt	**Lithium-ion** manganese	**Lithium-ion** phosphate
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	150 - 190	100 - 135	90 - 120
Internal Resistance in mΩ	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 - 300[1] pack 100 -130 per cell	25 – 75[2] per cell	25 – 50[2] per cell
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[3,4]	200 to 300[3]	300 - 500[3]	Better than 300 – 500[4]	>1000 lab conditions
Fast Charge Time	1h typical	2 to 4h	8 to 16h	1.5 - 3h	1h or less	1h or less
Overcharge Tolerance	moderate	low	high	Low. Cannot tolerate trickle charge.		
Self-discharge / Month (room temperature)	20%[5]	30%[5]	5%	<10%[6]		
Cell Voltage Nominal Average	1.25V[7]	1.25V[7]	2V	3.6V 3.7V[8]	Nominal 3.6V Average 3.8V[8]	3.3V
Load Current peak best result	20C 1C	5C 0.5C or lower	5C[9] 0.2C	<3C 1C or lower	>30C 10C or lower	>30C 10C or lower
Operating Temperature[10] (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C		
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[11]	not required		
Safety	Thermally stable, fuse recommended	Thermally stable, fuse recommended	Thermally stable	Protection circuit mandatory; stable to 150°C	Protection circuit recommended; stable to 250°C	Protection circuit recommended; stable to 250°C
Commercial use since	1950	1990	1970	1991	1996	2006
Toxicity	Highly toxic, harmful to environment	Relatively low toxicity, should be recycled	Toxic lead and acids, harmful to environment	Low toxicity, can be disposed in small quantities		

1) Internal resistance of a battery pack varies with mAh rating, wiring and number of cells. Protection circuit of lithium-ion adds about 100mW.
2) Based on 18650 cell size. Cell size and design determines internal resistance. Larger cells can have an impedance of <15mOhms,
3) Cycle life is based on battery receiving regular maintenance. Failing to apply periodic full discharge cycles may reduce the cycle life by a factor of three.
4) Cycle life is based on the depth of discharge. Shallow discharges provide more cycles than deep discharges.

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[12] *http://www.batteryuniversity.com./partone-3.htm*

5) The self-discharge is highest immediately after charge, and then tapers off. The capacity loss of nickel-cadmium is 10% in the first 24h, then declines to about 10% every 30 days thereafter. High temperature increases self-discharge.

6) Internal protection circuits typically consume 3% of the stored energy per month.

7) The traditional nominal voltage is 1.25V; 1.2V is more commonly used to harmonize with lithium-ion (3 in series = 3.6V).

8) Lithium-ion is often rated higher than the nominal 3.6V. Based on average voltage under load.

9) Capable of high current pulses; needs time to recuperate.

10) Applies to discharge only; charge temperature range is more confined. Delivers lower capacity at lower temperatures

11) Maintenance may be in the form of 'equalizing' or 'topping' charge to prevent sulphation.

Usually for small low power gadgets where compactness is highly demanded e.g. cellphones, lithium–ion batteries are the norm, whereas for slightly bigger appliances such as hand held devices (e.g. cameras), NiMH batteries are currently used. (NiCd batteries are also still on the market, although because of their “memory effect” problems, they are not preferred. Unless there is a major breakthrough in their R&D, NiCd batteries are on their way out.) For yet bigger stationary or non portable gadgets of any size, (e.g. stationary household gadgets and back up power systems) Lead Acid batteries are the most used. Because of their high power density, Li-ion batteries are also now being considered as mobility batteries for use in electric and hybrid vehicles. Such mobility batteries will be more interesting for PV when PV powered electric charging stations (the equivalents of petroleum filling stations) enter into the main stream. In the course of this thesis, different types of rechargeable batteries are considered in relation to the function of the PV powered appliances being discussed.

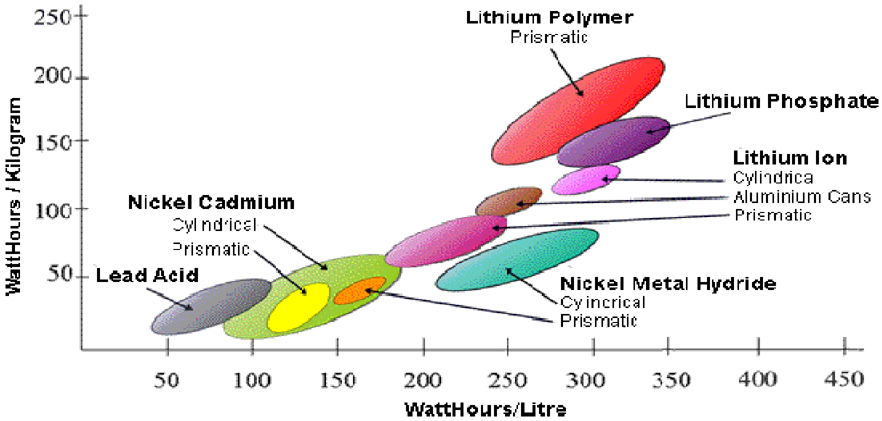

Fig. 2.6: Relative Energy Density of Some Common Secondary Cell Chemistries [13]**[10]**

2.8.1. The vanadium Redox Flow Battery (VRB)

A new type of storage battery, the **Vanadium Redox Flow Battery (VRB)** has been developed and is in the early stages of commercialisation and application in large scale PV and Wind Power fields. This type of battery stores energy in form of charged electrolyte that can be separately stored and only pumped through the electricity generating “battery plates” whenever the energy is needed. Its storage capacity is proportional to the volume of the stored electrolyte. Therefore a small battery size can be used and the capacity can be separately expanded by just adding the amount of stored charged electrolyte. It has the advantage of being able to be instantly recharged just by mere exchange of the electrolyte either by change of whole containers, such as is done

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[13] http://www.mpoweruk.com/chemistries.htm

with domestic gas cylinders in many tropical countries, or by filling up previously emptied fixed containers, just as is done with liquid fuel tanks in automobiles or domestic liquid fuel cookers and burners also common in developing countries. In the latter case, however, the fuel is used up in the energy generating process, whereas in the VRB the "spent" electrolyte is not used up but is simply "discharged" and so it has to be carefully drained for recharge at another PV station, if necessary. In a typical stationary installation, however, the charge and discharge of the electrolyte may be carried out at the same location either into separate containers by a "pump-out-pump-in" mechanism, or using the same containers by normal electrolyte recycling.

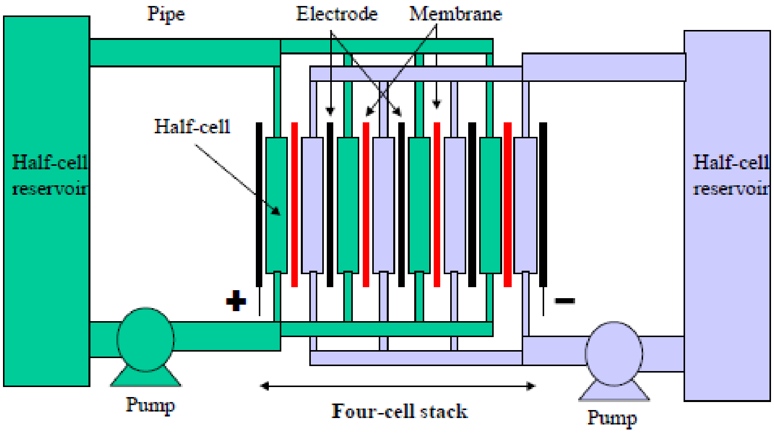


Fig. 2.7: Simple representation of the Vanadium Redox flow Battery (VRB)
Hawkins (1998)

2.8.2. High Speed Flywheel Energy Storage Devices

Another energy storage device that is also considered to be suitable to work with PV is the High Speed Flywheel which is currently under testing. This device works on the well-known principle of mechanical energy storage by means of a rotating mass. Although flywheels have long been in operation, they have always been limited by their bulkiness and slow speed and have always been used to bridge short energy loss intervals in mechanical devices. With advance in materials technology however, it is now possible to store relatively big amounts of energy in a compact flywheel rotating at very high speed (angular velocity). According to *Hawkins (1998)* quoting *Hockney & Driscol (1997)* flywheels rotating at around 30,000 rpm and storing about 2kWh have been reported to be under test runs providing emergency back ups at remote telecommunication stations in the USA. For safety reasons the flywheel assembly is kept underground as depicted in Fig. 2.8.

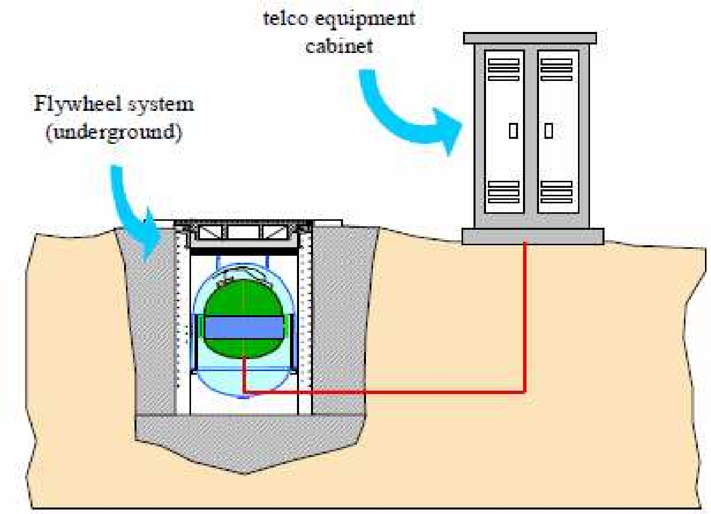
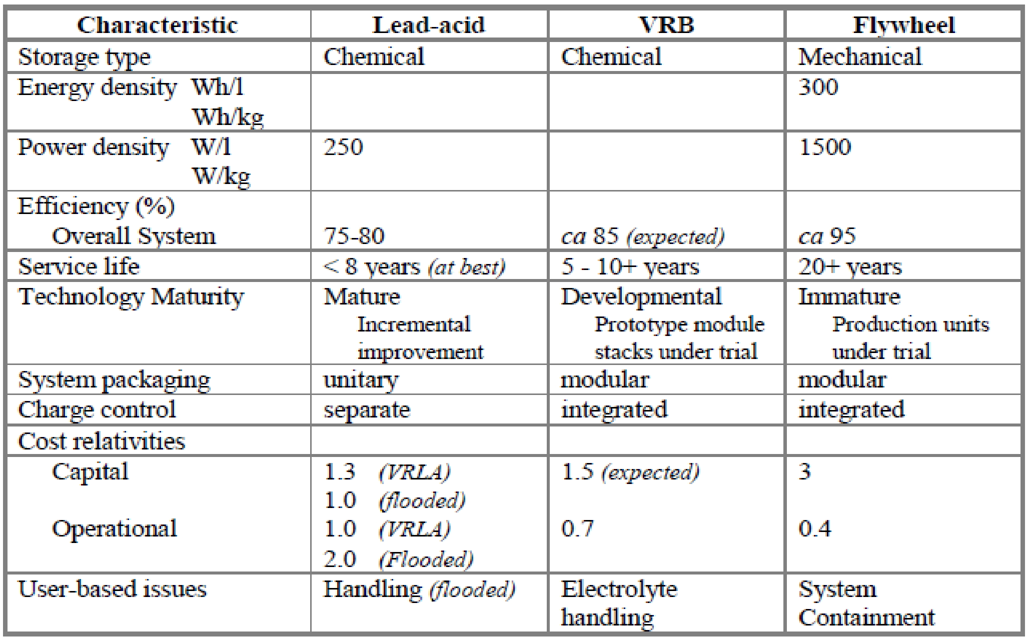


Fig. 2.8: Underground installation of a flywheel energy storage device providing back-up to a remote telecommunication station *(Hawkins, 1998)*

The vanadium flow battery and the flywheel storage systems are especially interesting for large scale stationary PV systems, the type that is suitable for large scale government services such as schools, hospitals etc. Since they are just now going into operation, they would be good to deal with for experimental purposes and for their characterisation for tropical applications. Following hereunder is a comparison with the more established Lead-Acid battery storage systems

Table 2.2: A comparison of the Lead-Acid Battery with the latest energy storage systems. *(Hawkins 1998)*



Characteristic	Lead-acid	VRB	Flywheel
Storage type	Chemical	Chemical	Mechanical
Energy density Wh/l Wh/kg			300
Power density W/l W/kg	250		1500
Efficiency (%) Overall System	75-80	*ca* 85 *(expected)*	*ca* 95
Service life	< 8 years *(at best)*	5 - 10+ years	20+ years
Technology Maturity	Mature Incremental improvement	Developmental Prototype module stacks under trial	Immature Production units under trial
System packaging	unitary	modular	modular
Charge control	separate	integrated	integrated
Cost relativities			
Capital	1.3 *(VRLA)* 1.0 *(flooded)*	1.5 *(expected)*	3
Operational	1.0 *(VRLA)* 2.0 *(Flooded)*	0.7	0.4
User-based issues	Handling *(flooded)*	Electrolyte handling	System Containment

2.9. PV Hybrid systems

Hybrid electric energy systems in general are those electricity generating systems in which more than one type of energy generation source is used in a commonly controlled utility system. PV hybrid systems are such hybrid systems in which PV is one of the component electric energy sources. Examples are of hybrid systems include, wind+diesel, and PV hybrid systems include PV+diesel, PV+wind+diesel etc. In such systems the diesel generator is incorporated into the system to take care of peak loads and less sunny days when the energy stream from renewable energy sources does not match the energy demand and the deficit cannot be compensated from the energy reserve in the battery storage system.

Sometimes, the fossil fuel generators may be modified to run on **plant oil** (e.g. from *Jatropha curcas*) or other **biodiesel** mixtures for diesel engines, on **bioethanol**-petrol mixtures if they have petrol engines. Bioethanol can be easily produced as a by-product from the sugarcane industry. There is also the possibility of ethanol supplanting sugar as the main product produced from sugarcane and this may have far reaching implication and reverberations impacting the price of sugar on the world market, and the lives of the sugar producers themselves, but that is beyond the focus of this thesis. The study of the optimization of the biofuels and engines to suit their purposes is also beyond the scope of this thesis but it is important to note here that currently (2007) there is great industrial interest in this field, spearheaded by the transport sector. Research in this area is brisk and prototype engines and vehicles have been developed. In power generation in Tanzania, there are just a few examples of PV-hybrid systems installed in some places. The Mbinga girls' school run by Benedictine Sister in Ruvuma Region in Southern Tanzania is presented in this thesis as a case study of PV-Biodiesel hybrid case study.

Moreover, in a PV-diesel hybrid system, with specially modified engines, the diesel may be replaced by or blended with a biomass based fuel from natural oil eg Jatropha oil. This has the advantage of reducing both greenhouse gas (GHG) emissions, saving of money especially in countries without their own oil reserves and greater independence from external oil suppliers and the associated problems.

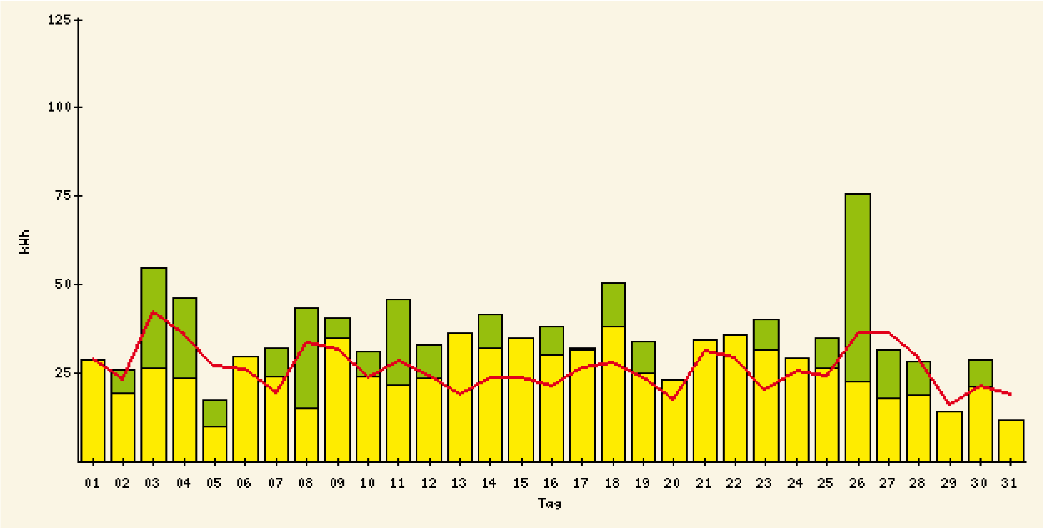


Fig. 2.9: Example of a combined performance of a PV-(bio) diesel hybrid system in Mbinga, Southern Tanzania in Jan. 2008-02-28 [14] [11]
(The yellow is the PV input, the green is input from the plant oil diesel)

The question of Bio-Energy Farming in Africa is still controversial. It is especially very interesting to African governments and the official community of European Development Partners, but to some others the quest for food cultivation for local self sufficiency in food as well as land management and conservation is of special interest. Debates are still raging. As late as February 2008 a seminar was organised in Dar es Salaam by the Dutch Renewable Energy Agency SENTER-NOVEM encouraged cultivation of Jatropha for powering activities in the Netherlands. Some documents from the seminar available on the SENTERNOVEM website state categorically about the dutch-centered interest in African fuel crops plantations in Africa. [[15]]

Some other powers are more preoccupied by China's "encroachment on their spheres of influence" in Africa and exploitation of the still cheap African natural resources and are proposing co-operation with China in this aspect *(TERRA DAILY, 2008)*[[16]]. However the voice and interest of the Africans themselves are falling far behind. It is high time the interests of the tropical developing countries themselves and their peoples were put to the fore.

2.10. The Missing Information

Most of the information available about PV utilization in tropical developing countries deals with the individual consumer, whether it is a physical person or an isolated localized small organisation, but not a government service system. Government service systems represent a unique group of PV users, with the advantage of nationwide hierarchical organisation, high community visibility and social impact as well as the support and the backing of the state. Using the structure of the government of the United Republic of Tanzania as a typical example this work, therefore, fills this knowledge gap by examining the application of PV all social and state services organised and supervised under the various government ministries, and delineates the role of the ministries in promoting the wider use of PV in order to improve delivery of their services to the public.

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[14] www.sonne-ueber-mbinga.de/diagramm.php?prev

[15] www.senternovem.nl/energising_development/workshop_on_biofuel_production_from_ja tropha.asp

[16] http://www.terradaily.com/reports/EU_nations_want_cooperation_with_China_on_Africa_ ministers_999.html

Summary of Chapter 3: Using the Tanzania Government as a model of a tropical developing country, this chapter present a general discussion of the role and potential of PV application by government ministries in Tanzania, the impact of PV utilization in the activities of each ministry and the role (if any) of the ministries in promoting PV utilization**.**

3. POTENTIAL FOR PV UTILISATION IN GOVERNMENT SERVICES PROVISION: A MINISTERIAL ROUNDUP USING THE TANZANIAN GOVERNMENT SETUP AS MODEL

3.1. General

A government as an instrument of the people, for the people and by the people has a definite role to play in the development of the people it serves and represents. The main aim of this chapter is to give information about the actual and/or potential role and impact of PV application in Government activities and function through its various ministries and their respective lower instances. In connection with this, information about the role of each relevant government ministry in promoting PV as an energy alternative is presented. Then in the following chapter some key government services, namely education, healthcare, and public administration (under appropriate ministries) are presented as deeper case studies.

3.2. The prevailing situation in Tanzania

Throughout the research period for this thesis (2004-2008) most PV related activities in Tanzania, were mainly initiated and/or carried out mainly by extra-governmental agencies, such as religious organisations, local and foreign NGO’s, or private individuals and are funded by various donor agencies and voluntary organisations. Supervision of project implementation is usually through local and foreign NGO’s or foreign aid agencies such as GTZ, DANIDA, USAID, SIDA etc. Direct government involvement is mainly in collaboration with these foreign donor or UN agencies. Various Tanzanian academic institutions have also been involved but to a lesser extent, except for a recent government drive to involve Teacher Training Colleges spearheaded by SIDA, where PV is correctly viewed and used as a means of providing reliable energy supply for running Information Communication Technology (ICT) projects in selected teacher training colleges, especially in remotely located centres. Besides domestic lighting and medical refrigeration, which are currently the main applications of PV technology in many parts of Africa including Tanzania, the powering of ICT is bound to become a major area of PV applications especially in conduction of Government Services, for both social welfare (e.g. Health and Education) and Public Administrative functions.

Africa’s experience in use of ICT in government administrative systems is currently in its initial stages and is, therefore, still very limited. The oldest widespread experience in computer use in a

Government administrative system in Africa, was by the then South African government during the infamous apartheid era, where it was used in various ways to facilitate the oppressive state mechanism in that country at that time. This negative use of (mainly American) computer technology in supporting the oppressive apartheid regime, was well documented by Stanford University computer science students [[17]]. However, computer application in government administrative system need not be oppressive only. On the contrary, it can be used for enhancing positive government services such as record keeping, government communications, government accounting etc. However, given the limited extent of the grid power supply and wire based telecommunications networks, computerization of government activities in such "unconnected" areas was, until recently, impossible. On the other hand, in fairly recent times, development of modern wireless data communication technology, has simplified the communication network potential, provided there is power to run the communication appliances themselves. That is where PV comes in. With PV technology and the favourable natural conditions of almost certain daily intense insolation leading to big annual Solar harvests, (1700-2200 kW/m².a in tropics as against 900-1150 kW/m².a in Temperate countries e.g. Germany) *(Hagemann 2002)*, decentralised generation provision of power to run the communications appliance is quite possible and at reasonable cost both financially and environmentally. The idea of PV utilization in tropical countries is not new, what is new however, is the widespread use of PV for powering of ICT. PV market studies have been conducted before, but not quite regularly. Among other activities a brief summary of the then current (2005) state of PV affairs in Tanzania was given by *Sawe (2005)***.** It is to be hoped that in future one will be able to get more information on Tanzania including most recent data in the PV market situation at this site. Using the Tanzania Government a san example, following hereunder is a government round-up in which the roles of the various government ministries either as users or as promoters of PV are described.

3.3. The Tanzania Government ministerial set-up vis-à-vis PV application

3.3.1. President's Office

The President's Office is the main coordinating body of all affairs of national interest and government activities. In addition to coordinating presidential activities it has, several specialised departments. Normally, the President's offices and their department are located in the Capital and a few big cities and power supply to these offices is well-taken care of from conventional sources (grid and stand-by diesel). Installation of PV in the buildings belonging to the President offices can be made only on environmental grounds or just as a way of setting a good example. On the other hand, there are several roles the President's Office can play in promoting PV. The roles of the different departments are as indicated hereunder:

- Department of Good Governance
    - Approval of PV friendly legislation
- Department of Politic & Social Relations
    - Expression and demonstration of political will for development and utilisation of PV in Tanzania
- Department of Public Service Management
    - Policy development for PV utilisation in Public Service

3.3.2. Vice President's Office

The Vice President's office is responsible for Union affairs and Environmental matters, both in policy and activities.

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[17] http://www-cs-students.stanford.edu/~cale/cs201/apartheid.comp.html

- Department of Union affairs:
    - Although this department does not seem to have direct PV-related activities or responsibility it can play a big role in co-ordinating PV related activities on both sides of the United Republic, i.e. for both the Union and Zanzibar Governments.
- Department of Environment:
    - This government department can be very useful in promoting PV and its application in Tanzania, building its case from the Environmental angle.

3.3.3. Prime Minister’s Office

The prime Minister’s office is responsible for overseeing activities of all other government ministries as well as government business in Parliament.

- **Department of Parliamentary affairs:** This government department can promote PV application in Constituency Offices of Members of Parliament (MPs’) since most parliamentary constituencies in Tanzania are located in rural areas that are currently not electrified. As a result, PV application to power ICT tools (computer networks and peripheries) in these offices, can facilitate Parliamentary documentation and communications systems linking the constituency offices with other government departments within the local area (i.e. constituency), district and regional headquarters up to the top government offices and parliamentary offices in the national headquarters. (i.e. both Dar es Salaam and Dodoma in the case of Tanzania). This office may also play an important role in promoting PV by leading the development of PV friendly legislation, such as grid feed-in and green electricity subsidy legislation.

- **Department of Regional Administration & Local Government:** The department of Regional Administration and Local Government in the Prime Minister’s Office (PMO-RALG) is the principal Central Government organisation overseeing all public administrative matters in Tanzania. More about the functions f this department and the role of PV comes later as a Public Administration case study.

3.3.4. Ministry of Infrastructure

PV in Telecommunication in Tanzania: There is great potential for PV utilization in the telecommunications industry especially in the powering of remotely placed telecommunication towers and microwave relay stations. This technology is already being used in Tanzania, Uganda and many other African countries. The role of PV in charging small cellular phones for people in remote locations has not been fully exploited yet. In the cellphone charging business, especially for people in rural and remote rural areas, the only foreseeable major competitor against PV in charging of cellular phones (and other small electric gadgets such as small radios, etc) is the **hand winding dynamo charger**, going by the name of **“freecharge”** such as the ones depicted below (with proper design and operating characteristics, such cellphone charges have a potential market in remote areas):

Fig. 3.1: Hand winding cellphone chargers

Commercial description of the left depicted cellphone charges is available respectively at [18]: The right depicted cellphone charger, was ordered and tested by this researcher and was found to be **inadequate for rural application**. It seems that the charger was conceived to be only an emergency tool for helping somebody to deliver a small charge level into a cellphone battery enough to make a single call in case of emergency. Such a hand powered "emergency charger" is conceived for users in developed countries where make a person temporarily stranded in a remote area needs to make just a single call in order to get the much needed help to bring him/her back into an area serviced with all facilities including grid electricity for standard cellphone charging. Cellphones are becoming even more important as instruments for money transfer to third world countries as they are objects of communication. A recent report by the Washington post demonstrates how this transfer is effected. [19]

PV enabled internet connectivity: The question of **Internet Connectivity** for tropical developing countries looms large in the whole body of this thesis. Developing countries are the junior players in the internet game. This is what is called the **"digital divide".** Ranking the junior players, i.e developing countries Africa is even lower on the ladder. According to *Lalana (2003)* "…only 10% of world population is online ... most internet users are in the developed Western countries: the US, Canada and Europe account for about 63% of the world's internet users. The Asia-Pacific's share is about 30%. **Africa and the middle-East combined account for less than 2% of the universe of internet users."**

There are many reasons accounting for this problematic situation and in the opinion of this researcher, power poverty is among them. In their final report to a survey of ICT needs in Tanzania, LAMTRAC [20], a Swedish company tasked for the job, mentions unreliable power as one of the major constraints working against ICT development in Tanzania, *LAMTRAC (2001)***.** What they failed to mention, however, is the fact that the bigger part of Tanzania is not even connected to this "unreliable" power supply. Efforts are being made to improve the African and indeed, the East African and Tanzanian connectivity situation, but still reliable electric energy supply for proper function of the necessary Information and Communication Technology (ICT) hardware is still a problem. It is especially important to note that PV can play a vital role in powering ICT since most of the associated installations are low power and distributed in area coverage especially where rural connectivity is concerned. Quite unfortunately, however, most work written about rural connectivity does not adequately address the power supply question. A typical example would be *Sheriff (2007)* in his "thematic report" on rural connectivity in Tanzania, produced for the International Institute for communication and Development (IICD). Moreover Much of ICT development and its link with Photovoltaics will be discussed in proper case study sections, but here suffice it to present a summary of the efforts being generally made by various agencies

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[18] www.solarcosa.de/Shop/Motorola_FreeCharge.cfm?id=186

[19] www.washingtonpost.com/wp-dyn/content/article/2006/10/02/AR2006100201462_2.html

[20] www.lamtrac.se

to bring the whole of Africa, East Africa and Tanzania in particular onto the **Global Information Super Highway**. The key undertaking for this work revolves around a project now in in progress, going by the name of **The East African Submarine Cable System (EASSy)**. Most current information about it may be obtained from [21]. A picture of the project and planned connectivity is given below. According to *Yonazi (2005)***,** most of the work as depicted in the maps below, is being done through **private companies** and international organisations specifically related with provision of such services in order to facilitate this connectivity. The main advantage of this arrangement is harnessing the vibrancy and effectiveness of private enterprise, but this also comes at a cost. The profit motivation of private enterprise may hinder extension of the necessary infrastructure for public provision of e-services in rural and/or economically disadvantaged areas unless the governments institute special measures through their respective regulatory and executive agencies as well as economic/financial incentives to lure the private enterprises to such disadvantaged areas.

The costs of installation and operation of computer networks are high. This is one factor hindering faster growth of internet services worldwide, but especially so in underdeveloped Third World countries including all countries in the East African Community, namely: Tanzania, Uganda, Kenya and, since recently, Rwanda and Burundi. As a way of reducing internet costs, governments should invest in energy efficient computers and network components and related research. In the case of lack of research funds and facilities, government ministries for communications and technology could keep a watchful eye and monitor available on-going research in this field. A comprehensive tracking of developments in this field is carried out by the energy efficient internet project at the University of Southern Florida in the United States from whose website a lot of literature on this issues is available, as seen on the following link [22].

More information about the impact of ICT can be obtained from other research centers and thinktanks, such as the Wuppertal Institute for Climate, Environment and Energy. *Kuhndt et.al (2006)* from that Institute, for example have recently published a complete assessment of the contribution of ICT to the Millenium Development Goals (MDGs), in which they cite both positive and potentially negative impacts of ICT [23].

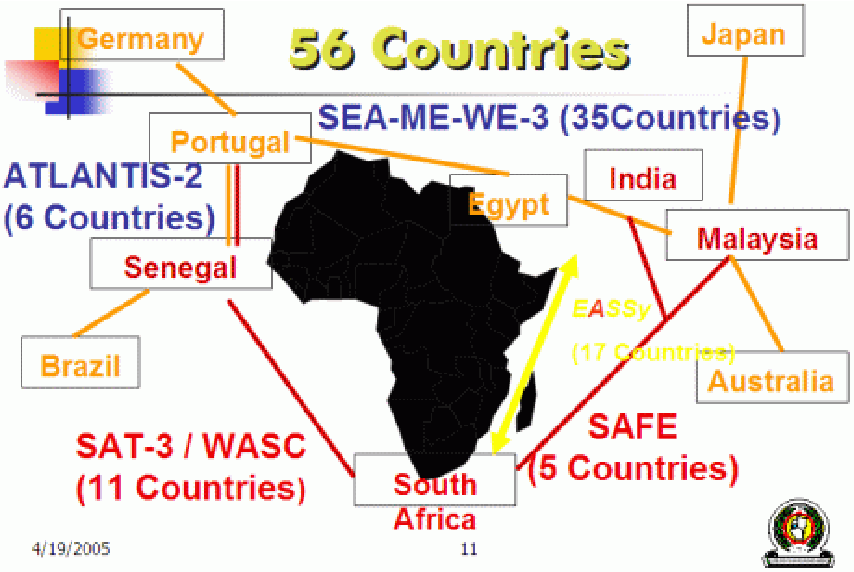

Fig. 3.2: Africa in Global Fiberoptic cable Internet connectivity plan

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[21] www.eassy.org/

[22] www.csee.usf.edu/~christen/energy/lit.html

[23] www.csee.usf.edu/~christen/energy/lit.html

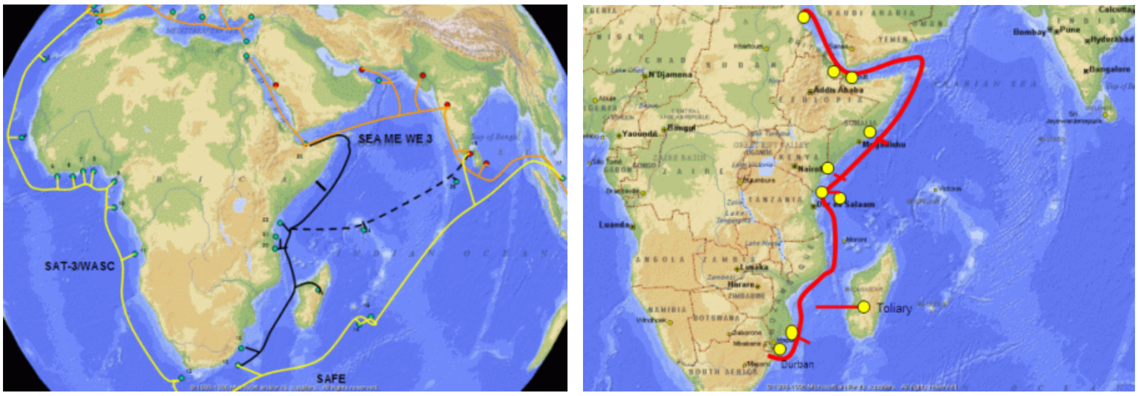

Fig. 3.3: Submarine cables around Africa: existing, planned and currently under construction ***Yonazi (2005)***

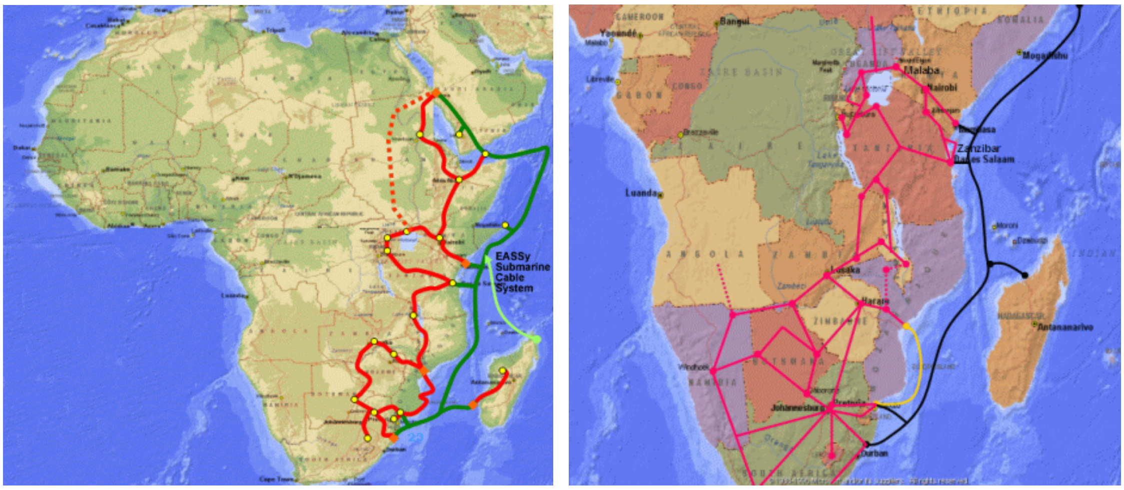

Fig. 3.4: EASSy backhaul options under consideration ***Yonazi (2005)***

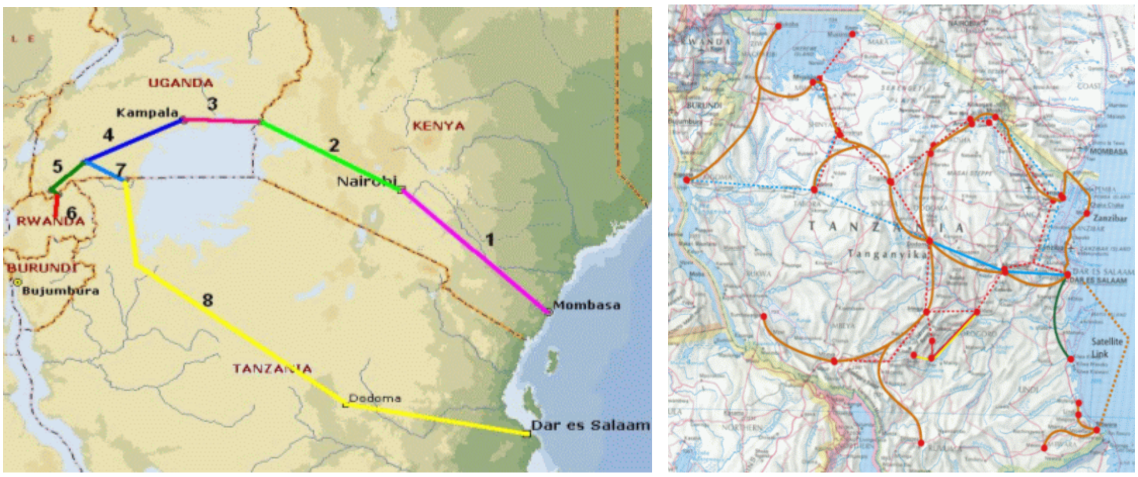

Fig. 3.5: Closer to Home. The East African task force ***Yonazi (2005)***

In October 2007, the ITU organized the “**Connect Africa Summit**” in Kigali Rwanda in which it was noted that Africa is not only lagging behind the rest of the world in ICT but actually falling back despite the investments that have taken recently place. A “Marshal plan” was proposed to make the difference that would ensure Africa meets the Millennium Development Goals by 2015 *(ITU 2007)***.**

In a country/continent without reliable electricity supply, the digital divide will even be grater. On the other hand, given the amount of sunshine that Africa receives annually, a parallel investment in PV development and installation in Africa will make possible the realisation of this “Connectivity miracle.

- **PV in railway transport:** Some stations on the Tanzania-Zambia Railway (TZR) had PV installation to power communication and facilitate local electricity supply.
- **PV in Road transport and fuel dispensing:** Whenever there are power-cuts in Tanzanian cities some petrol stations fail to work. PV could help run some of the most essential services such as fuel dispensing and air compression.
- **PV in Marine services:** Marking of waterways and lighthouses for marine operations is already a well developed industry. Respective government ministries and other state and private organisations need only to tap into this market for their own benefit.
- **PV powered airstrips and ground systems, especially in remote rural centres:** Development and constant improvement of the LED based lighting systems will prove to be beneficial for the purposes of airport marking of various objects at airports aerodromes and airstrips, especially in remote areas of Africa and other tropical developing countries. This would enable night flights to these areas leading to improved services. However, this development may also have its dangers in facilitating nocturnal illegal activities such as drug trafficking, weapons and mineral smuggling which has been the bane of tropical developing countries in recent and modern history. So states need to be more vigilant on this.
- **PV powered aviation services:** PV as a direct flying power source for aviation in the sense of air transport is not yet developed. However research for use of PV in preparation of aviation fuel is under way. Direct PV power for small unmanned special purpose aircraft has been under consideration for quite sometime, mainly for use in outer space eg Venus, but the same technology could be used for terrestrial applications such as geo-survey and agricultural research.

3.3.5. Ministry of Industry Trade and Marketing

- **Development of industrial base for greater utilisation of PV in Tanzania**: Currently most of the PV used in Tanzania caters for domestic use, mainly domestic lighting and some refrigeration. Outside the home, PV is used mainly in medical refrigeration. However, if PV is to gain any strong foothold in tropical countries, this situation aught to change. Some industrial and other productive applications must be developed. For example, 12V electric motors and lighting systems for sewing machines could be very useful in enhancing the rural base for the garments manufacturing industry. Establishment of a collection and marketing system for the garments so made would increase the benefits to the producers thereby creating an empowering situation for more investment into PV for the rural based garments manufacturing industry. The ministry could play a vital role by supporting the development of such manufacturing and product collection and marketing systems.
- **Promotion of Manufacturing and Trade in PV products in Tanzania:** Almost all elements of PV systems used in Tanzania, from Modules to BoS components are imported. The ministry could develop policies and economic incentives conducive to the local manufacture of PV system elements. A more elaborate proposal along these lines was developed by *Byabato (2000)*
- **PV powered ICT in trade and e-commerce**:As discussed before under the ministry of infrastructure, the most important application of PV in transformation of rural life and fighting technological underdevelopment will be the application of PV in ICT and therefrom associated e-commerce. The ministry could promote this development by enacting appropriate policies and instituting conducive economic environment.
- **PV powered ICT in trade documentation, inventory management (esp. just-in-time supply chains management) etc.** By mainstreaming electronic documentation processes,

the ministry could indirectly influence PV application in areas where PV will be powering the necessary ICT hardware.

- **Promotion of PV through Energy Trade policies and trade promotion measures**. The ministry could do a great service towards promotion of PV applications by instituting conducive **Sustainable Energy Trade** policies and sustainability promotion measures such as introduction of **Renewable Energy Certificates Systems (RECS), Guarantees of Origin (GoOs),** and special energy trade labels such as **OK power labels,** or something similar to **TUeV-certified power labels** common in German speaking countries of Europe, or institution of **Environmental Product Declaration (EPD)** documents. Such trade mechanisms are already being used in Europe to promote renewable energy utilisation and related Energy Trade and **Carbon Trading** or **Emissions Trading.**

3.3.6. Ministry of Livestock Development

- The role of PV in general life of people in predominantly Pastoral Communities e.g. in Maasailand, Sukumaland. In addition to the quasi-traditional role of lighting in all rural communities, PV powered cellphones could be used by herdsmen in the field in pastoral communities for communication with the home base or with other herdsmen on the move, or to get information about market conditions for their animals before they go to animal auction markets, which can be far away.
- PV powered water supply schemes for livestock management. In addition, the ministry could organise for construction and maintenance of PV powered watering points for animals at various locations so that people in pastoral communities could come and water their animals, (of-course for a fee).

3.3.7. Ministry of Health and Social welfare

- The issue of PV in healthcare is being treated separately in the next chapter as one of the selected case studies. Here only short notes are given about social welfare:
- **PV in Social welfare**: There are a number of projects in which PV can be of much use in the National Welfare System. One obvious application is illumination in many National Welfare Institutions (NWI) such as various homes for people with problems, juvenile offenders' jails etc. Another example is powering of ICT in the same institutions and their networking and link up with Headquarters, especially those that located in remote places. Some of the National welfare institutions do have educational and training facilities of various types and levels, as well as similarly diversified health facilities. In such institutions PV may play a pivotal role in enhancing their efficiency and effectiveness, just like in other similar institutions under respective government ministries.

3.3.8. Ministry of Justice & Constitutional Affairs

- **PV powered ICT in justice delivery systems**. Justice delivery in many Developing Countries including Tanzania has a lot of problems, of which energy supply, documentation and communication, are just but a few. (Others include buildings, personnel). It is an overburdened system. There is a great backlog of many pending cases which need adjudication. PV and ICT offer a combined solution to energy, documentation and communication problems, the effect of which is a speed up of “due processes” taking place in our court systems. A simple SHS (PV modules, lights, controller with or without inverter, a battery, and a power outlet socket), offers opportunity for electric lighting, and powering of laptop computers, thus enabling personnel to work faster and for longer periods, even utilising night time, especially when consulting legal documents or reviewing previous court cases, which can be made available in electronic form (e.g. on CD-ROM). Addition of a communication facility on this basic infrastructure, (beginning with simple wireless communication, through to specialised “thin client” internet facilities) will increase the ease of communication between different instances of the judiciary and thus reduce state costs and delays of justice delivery. For example, a system can be established that any judgement made by a primary court magistrate can be immediately electronically transmitted to the district court on the same day for the necessary case review. The same would apply for district, resident magistrates’, and high court cases with respect to their higher instances as provided for by the law. Power availability through PV would enable the Judiciary to employ a simple Computer based Case Management Application (CMA) such as the one described by *Blackton (2001)* in the whole country thus speeding up cases hearing process and monitoring tracking down and eliminating all sources of delay. Currently, a lower court judgement review has to wait for an unspecified time either until an inspection is organised or until unusual circumstances necessitate a speedy revision. It is on record that a few cases were speedily reviewed under unusual circumstances. One of the fastest reviewed case was that of Republic vs. Dibagula which was a result of public outcry and a nationwide demonstrations that threatened communal peace and political stability as Muslims all over the country demonstrated against the government after Dibagula was jailed for alleging that “Jesus was not God”. Other instances that precipitated speedy case reviews ware press furores that followed the infamous cases of “Immigration: the Dog” in which a dog was “sentenced” to death by a court magistrate for the “crime” of being named “Immigration” or the imprisonment of Journalist Adam Mwaibabile for the “crime” of exposing state secrets after he published in a newspaper an unfair order against him, by a senior government official. *Ngaiza (2000)***.** If, for example, Mwaibabile had not been a famous journalist, and if the press had not made such big noise about his imprisonment, then he would have languished in jail for a longer period until a routine review was carried out or an appeal had successfully sailed through the “due process”. An analogy into Kenyan politics was later drawn by *Ngunyi (2002).*

- **PV+ICT in the appeal process in court cases:** Another positive effect of PV powered ICT in the judiciary will be the speeding up of the appeal process. Once again usually, after a judgement is made and pronounced in court, then that judgement is immediately executed, irrespective of whether the judgement papers are printed out or not, but the appeal process has to wait until a “copy of the judgement” can be provided by the court to the prospective appellant. This process of preparation, print out and issue of “judgement copies” usually takes a few days or weeks (or months, sometimes). This delay sometimes provokes (sometimes successfully) some corrupt business of bribery whereby one of the belligerent parties may be tempted to contact a (junior?) court official (ostensibly in order to “speed up” or “further delay” the matter, or tamper with evidence or the justice delivery system itself, as the case may be). Providing PV powered laptops (part of ICT), would enable our law abiding judiciary personnel to execute their duties diligently without any delay and this would deny the (usually very few) corrupt ones a simple excuse for demanding bribes. (of course since the vice of corruption is like the legendary a many headed *“Chimaera”;* they can think of other tricks.) In any case, in order for this system to be successfully set up and run smoothly, knowledgeable personnel have to be trained, which leads us to the second project described hereunder.

- Taking just one issue of drugs related cases in Tanzania, the following example may serve to illustrate the tough situation facing the Tanzanian justice system: A famous member of Parliament, the late Ms Amina Chifupa stated that according to 2005 statistics, 3, 368 cases involving 4,532 suspects went to court in connection with 150,000 kg of Bhang , 1,200 kg of “Khat” *(mirungi),* 10 kg of heroin, 78 kg of processed bhang and 362g of cocaine and 1.4 kg of illegal morphine [[24]]. If the justice system is not helped in

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[24] http://www.ippmedia.com/ipp/nipashe/2006/11/28/79302.html

expediting the decision of such cases, by providing technical facilities, then many innocent people would suffer in unnecessary custody burdening the government with their care and fuelling corruption or worse still the government would be rendered ineffective and many illegal activities would go on unaddressed with grave consequences to the society as a whole. Fortunately enough it seems that the Tanzanian Justice system has become aware of the problem of technology in the judiciary. In underlining the importance of technology application in justice delivery system, the then new **Chief Justice of Tanzania, Augustin Ramadhan** was reported by *Chhatbar (2007)*, to have promised "… to make sure corrupt practices are not tolerated and **technology was applied**" and also insisting that "… **knowledge and use of technology in judicial work** [was] crucial for efficiency and effectiveness". This realisation, then, is a sign of changing times and a good beginning for establishment of a project such as one described hereunder.

- **Training of Justice personnel in working with ICT and PV:** In order to use PV powered ICT in the judiciary system of any third World tropical country (e.g. Tanzania) an elaborate training program for judiciary personnel in both PV and ICT must be started up. This can start with newly recruited judiciary trainees in respective institutions, just as it has been done in the Ministry of Education with teacher training institutions in Tanzania.

3.3.9. Ministry of the Public Security and Safety

This is a new ministry in charge Tanzania Police Force, after separating it from the Interior Ministry. According to Commonwealth Human Rights Initiative (CHRI) country report for Tanzania for 2006, Tanzania by 1999 had approximately 27,200 police officers which made a **police to population ratio** of **1:1,298** for a population 35,300,000. By 2003 this ratio had worsened to **1:1,400** grossly falling short of the **UN recommended ratio of 1: 450** *(Churi, 2006)*. The same report goes on to describe the grossly inadequate living and working conditions, as well as poor working tools that demoralise the police officers. These, together with other factors may contribute to unsatisfactory performance and may even contribute to some elements of corrupt behaviour within the police force. It is once again postulated in this thesis that **improvements of technical facilities** in both the domestic and working life of the police force, can greatly improve their working efficiency, and contribute to a reduction of "incentives, opportunities or loopholes for corruption" *(mianya ya rushwa)*. One of the proposed technical facilities in question is adequate power supply. Under this heading, PV either in stand-alone or in hybrid system may play an important role, in the rectification of the above stated problems. This situation is especially more appropriate for police work and residence outside big towns i.e. in rural and urban areas without a guaranteed grid power supply. Following hereunder are some examples of PV applications in police officers' residence and police work

- **PV application in police officers' living quarters:** PV, either alone in discrete units such as Solar Home Stystems (SHS), networked into micro- and minigrids, or in various hybrid systems can power lighting and some other domestic electricity needs as already described for other population groups, such as school teachers and medical workers. In some areas in Tanzania, for example, especially in some rural areas, police quarters are an integral part of colonial style government stations, which used to include schools, dispensaries, primary courts and other government services in one compound. In some other areas there are separate police living quarters, a form of police barracks officially called **"police lines"** housing police officers and their families, especially in urban areas. Under such arrangements it is easier to install and maintain a power supply system, that may include PV installations.

- **PV application in police work and forensic activities:** Application of PV powered computers in police documentation work would work just in the same way as has been described above for the judiciary, except that in this case the document preparation, transmission and retrieval would be in relation with police activities. (Transmission of police case files and other documents for legal action, Examination and search of legal reference material on CD-ROM or on-line for criminal case prosecution preparation, Internet search for additional forensic information and on-line training of police officers in forensic matters). Borrowing a page from the "**E-Policing Strategy Statement"** of the **Lincolnshire Police Department (UK) (2003).** The concept of using electronic information systems in police work is called **e-policing**, This strategic statement states its vision as a set of Strategic Business Drivers (SBDs), the principal one being "...the modernising government objective, as stated in the British cabinet paper of April 2000 called **"E-government: A strategic framework for public services in the Information Age"** in which other additional "business drivers" for introduction of e-policing are stated as follows:

- The need to work closely with other emergency services and public sector organisations to provide 'one stop shops' where inter-agency co-operation can lead to greater efficiencies and more 'citizen-centric' services;
- The Best Value Performance Indicators, against which the Force is measured and which demand a programme of continuous improvement;
- The growing customer expectation that the capabilities offered by technology will be exploited fully in the delivery of public services.

Needless to say, if tropical developing countries are to remain part of this world and their state agencies such as the police to be able to operate locally and internationally through international law enforcement agencies such as **Interpol**, they have to be able to acquire and use modern technology, such as ICT, slightly modified to be able to effectively and efficiently perform within the constraints of their environment. An additional motivation for introduction of e-policing is that police organs in tropical Third World countries must be able to speak with their counterparts in the more industrialised parts of the world "on the same wavelength" and using the same, similar or compatible working tools for ease of information transfer during collaborative activities such as tracking down of international criminals such as terrorists, drug traffickers and money launderers.

The e-policing philosophy of the Lincolnshire police department stated above should be an example for other Police Forces still lagging behind in this concept, such as we see in many Tropical developing countries such as Tanzania. However given the technical constraints of lack of reliable power supply and the natural endowment in Solar Energy resources, PV seems to be one of the ways out of the power problems to enable us to run e-policing serves. Additional innovations in police interaction with the public are as demonstrated in the following examples.

Example 1 The Police Hotline: In this example, members of the public are advised to call a certain police number whenever they are in danger or if they have grounds to suspect that a crime is taking (or is about to take) place. In order for the public to be able to do this, they must themselves have working telephones. In Dubai, for example people have the **Safer Community Card** which enables them to call the police from any public payphone or private cellphone any time. For this arrangement to be effective, there needs to be a working telephone network, people need to have affordable telephone gadgets themselves, and affordable means of charging their cell-phone batteries. Nowadays, the mobile phone revolution has already solved this question of physical availability of cellular phones gadgets; economics is in the way solving the purchase finance question for actual acquisition of the gadgets by the public. The only big problem is affordable charging means. Therefore a PV powered village cell-phone battery charging centre could help these rural people able to respond on the hotline. Otherwise the police hotline service will benefit only a few city residents with access to mains electricity in addition to accessing the cellphones themselves.

Example 2 Police internal communication: Most remote police posts have problems with communication with their local headquarters or higher administrative instances. This makes their task of policing and/or follows up on criminal acts and investigation more difficult. If all police posts could get PV powered communication facilities, then it would be possible to incorporate remote police posts into the current police intranet communication system. This would facilitate police work and help reduce the level of crime in the country which with has in recent times grown out of proportions, with the recently frequent Hollywood-movie-like bank robberies and other minor events.

Example 3 Road Patrol: Strategically located PV powered devices such as cameras and radar systems could actually contribute towards accident reduction by helping the police in detecting and finally arresting over-speeding and/or hit-and-run drivers causing unnecessary road accidents. Such hit-and-run road accidents (in which causative drivers don't show up at police stations) usually contribute to unnecessary deaths due to lack of first aid and/or quick and timely delivery of victims to hospitals. In most developing countries, even a simple accident can lead to a victim's death due to excessive bleeding or lack of other first aid, because of lack of adequate medical facilities. The few better equipped district, regional and consultant hospitals are very far apart and road traffic is so sparse, especially in countryside roads or remote sections of highways between two big urban centers.. It is, therefore, important that drivers of vehicles involved in accidents, if they are themselves not injured, carefully examine accident sites to help victims of such accidents before they move away. When a driver runs away from an accident scene without trying to help the victims, he/she contributes to the gravity of the accident in which he/she had been involved. Such a driver must be tracked down and prosecuted for the additional offence of failing to help a person (persons) in need, in addition to the original charge related to the main accident. Currently police have to use a lot of ingenuity to be able to arrest such hit-and-run drivers.

Example 4 Roadside telephone systems: PV powered roadside traffic telephone systems could be very useful in helping other safe and/or careful drivers, passengers and/or passers-by in reporting accidents and other road traffic problems (whenever they happen), especially on remote stretches of highway, passing through uninhabited territory. Such territories are very many in a country as big Tanzania, where one can drive for several hours on at full speed without meeting a single human settlement or even a single person. In such areas even cellular phone networks are not accessible and for obvious commercial reasons, are not likely to be installed in the near future. In the case of a problem developing to someone driving alone on such a stretch, the person would be stuck until another vehicle happens to be passing. Special traffic telephone systems are required along such road stretches. Similar telephone stations are already installed on major highways in developed countries including the US and Germany.

3.3.10. Ministry of the Interior

After separating the police force into a new Ministry, only Prisons, Immigration and Fire & Rescue services remained under this ministry.

- **PV application in the Tanzanian Prisons services**: Prisons services in many African countries, including East Africa and Tanzania in particular, date from colonial times. Working and living conditions for both prisoners and their Warders (and their families), most often are still in the same situations as they were left at the eve of independence. Some have even further deteriorated. During colonial times, the prisons services, just like any other services were meant to serve colonial interests. With independence, however, the mission and vision of the prisons services just as with any other government services ought to have changed, however in many aspects they have not. Some of the problems currently experienced by prisoners and the prisons administration systems could be solved by availability of good technical resources, the most important of which is reliable electricity supply through PV either alone or in hybrid systems (i.e. PV in combination with other energy resources). As mentioned elsewhere in this thesis, the principal uses of PV electricity are in lighting and powering electronic devices. The only difference is the application of the devices powered. In Prisons services, **security and surveillance** take a special role because of the nature of the institution itself. Lighting and electronic surveillance systems acquire a special operative role in the monitoring of prison inmates and maintenance of order among them. Telecommunication and other ICT should also play a very important role in day-to-day administration of prison services. All these demand availability of reliable electricity, albeit in low power, at every prisons location. In these circumstances, PV can play a decicive role and can make the difference between success and/or failure of a corrective penal service.

- **PV application in the Immigration services department:** Most immigration boarder post is located in remote places, far from major cities and/or human settlement stations without adequate and reliable power supply. In order to minimise operation costs, electricity when supplied, is in such places strictly and only for use in official activities, using small petrol generator sets. Immigration department workers and their families usually live and work for long periods of their active life under such circumstances. PV either in stand-alone form of Solar Home Systems (SHS), or in locally integrated microgrids using hybrid systems, may help alleviate their misery. For PV use in official activities the following examples will help illuminate the problems and their PV based technical solutions.

Fig. 3.6: The PV in use at the Tanzania-Kenya Boarder post at Namanga (by author, 2006)

Example: The Tanzanian Smart Card National ID System: Tanzania is now embarking on establishing a National Identity card scheme based on “Smart Card Technology which will be used for identification of Tanzanian national and illegal immigration control among other uses. *(Kimati 2007); (Daily News 2007)*. This system may work well if all concerned authorities had their electronic gadgets that could read the cards and communicate with central data bases. Given the electricity supply situation currently obtaining in Tanzania, the smart card system may not be effective in far flung and remote areas. On the other hand with a few watts generated from PV installations in the affected areas, these gadgets can be very useful not only in control of illegal immigrants but also in other national economic activities where citizens' identification may be necessary.

- **PV application in Fire& Rescue services:** Fire and rescue services are among the vital services necessary for developing and maintaining a vibrant economy because they help in saving life and property both of which are valuable to their owners and the nation as a whole. As stated under police and prisons services, PV may be used in office and administration work, in workers residences and in field operations and in other situations where such services are usually necessary in circumstances when and where standard electrical services may for various reasons sometimes not be available. Marine rescue, for example, may often be required at secluded remote beaches or fire fighting in a building in the city center, may serve as examples to illustrate the point. In most cases whenever a fire breaks out in a given building, electricity supply is among the first services to be affected. It is either deliberately or automatically switched off. In such circumstances there has to be independently powered emergency lighting systems. Such lighting systems are usually run from battery power packs which may themselves be kept charged by Photovoltaics

3.3.11. Ministry of Planning, Economy and Economic Empowerment

There role of PV for lighting and powering ICT in government offices cannot be further emphasized. However this ministry has a vital role to play towards enhancing wider use of PV in the country. **The role of PV in economic empowerment of Tanzania people:** can be summarised as follows:

- Training of people in installation and management of PV is a form of employment and enables both instructors and learners to enhance their income earning potential.
- PV business enhances incomes of directly PV related businesses eg traders and installation technicians & contractors.
- PV use enables other businesses through powering of communication devices (eg cellphones), various production gadgets eg sewing (machines) and lighting. Special emphasis on PV lighting follows:
- PV lighting has an important economic empowerment role as it enables prolongation of active time beyond sunset. This enables people to work longer hours during daytime as well as night time (as they are assured of night illuminated evenings they can extend their work time or reschedule some of the activities for time after sunset.
- PV enables education (PV lighting enables longer study time for students and evening preparation time for teachers, because of availability of night lighting). PV also gives possibility of using electronic edutainment facilities. Both these enhanced possibilities synergistically enhance the quality of teaching and learning and therefore the increase the potential of learners for future higher production capabilities and subsequently higher income through better qualifications.

Planning for economic empowerment of Tanzanians to acquire PV systems: Since PV systems are expensive, the government should devise ways of enabling the general citizenry to be able to acquire them. Tax incentives are already in place in Tanzania, through tax-free import policy for PV equipment, but they still have loopholes in interpretations. Moreover, as banks are not yet quite willing to lend money to would be PV systems buyers the government could plan and set up a clear policy, training and other incentives for commercial bank officials so that they can "see the light" and increase their willingness to lend money to equipment traders, buyers and installers, so as to facilitate further use of this free energy.

3.3.12. Ministry of Minerals & Energy

Tanzania is a rich country in terms of mineral resource endowment. It has energy minerals such as natural gas and coal, industrial minerals, precious metals such as gold and platinum and gemstones such as diamonds and tanzanite. A comprehensive picture of the Tanzanian mineral industry by 2003 is given by *Yager (2003)* in the US Geological Survey Minerals Yearbook 2003, available at [[25]]. Although not current, this report serves to indicate the actual wealth and potential of the minerals sector to contribute in the Tanzania's economic development.

This Ministry has two major directorates dealing with Energy and minerals respectively, but for practical reasons, some mineral resources developments are dealt with under other ministries as well. For example, development of the Liganga Iron-Ore and the associated Coal deposits at Mchuchuma are dealt with under the Ministries of Industry and Trade.

Trade in Energy minerals, together with other energy resources are regulated under the directorate of Energy. In recent times, the Government has established the Rural Energy Agency (REA) and the Rural Energy Fund (REF) to facilitate the supply of modern energy services in rural areas. According to a report by *ECON Analysis AB (2007)* both REA and REF are to be regulated under the Rural Energy board (REB) and their roles are delineated as follows: The REF is to financially support Rural Energy Projects especially electrification whose implementation is to be conducted mainly by the private stakeholders under the auspices of the REA. PV projects are among.

- **Government sponsored regional PV projects:** Currently, the Government of Tanzania, in collaboration with the Swedish International Development Agency (SIDA) are undertaking a series of marketing promotion for PV Solar Home Systems (SHS) mainly for lighting and home entertainment. Several projects are under way, especially in Mwanza region, South of Lake Victoria. More information about one such project in provided in the annex. In comparison to Tanzania, Kenya and South Africa are more advanced in such projects
- **PV use in the mining sector (e.g. small scale mining operations & miners' settlements):** PV can play a big role in the mining sector, both large-and small scale. In conjunction with rechargeable batteries (preferably NiMH), for example, PV can play a very important role in use in underground mines operated by **small scale miners,** from powering blasting equipment to lighting especially using LED lights. Given a proper commercialising system, PV charged mining lamps based on efficient LED lighting could be used by these small scale miners. A privately operated PV powered communal battery charging business may also thrive in these areas, creating further employment and improvement of living standards among the small scale miners. Such PV powered **underground miners lighting** will also contribute to improvement of the safety standard in the mines. In addition to lighting, PV may also be used in **air compression** and underground **water supply** for **mining technological** uses, as well as underground **mine ventilation** in which in the case of small scale miners, a communal but commercial system may be devised whereby the small scale miners do not need to invest in complete systems but only pay to cover part of the initial investment and for the services they use according to a previously agreed affordable payment system. For this to work, a proper financing system for initial investment and subsequent payments will have to be put in place. This can be part of the already existing (or soon to be established) general banking system serving the small scale miners. Currently the situation is very pathetic indeed. Among small scale miners, safety standards are very low and operating costs are very high, a situation which results in unprofitability of small scale mining activities and unnecessarily high accidents, morbidity and mortality rates and resultant poverty usually associated with small

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[25] http://minerals.usgs.gov/minerals/pubs/country/2003/tzmyb03.pdf

scale mining activities. Currently, small scale miners for lack of proper tools use ordinary surface torches with ordinary non rechargeable dry cells which don’t last very long despite the fact that they are bought at very high prices, due to the remote location of the mines themselves. Proper mine ventilation systems are inexistent, crude or outright improper equipment are used. This researcher recalls a visit to a high grade Tanzanite (a Gemstone) mine at Merelani, in Northern Tanzania, run by small scale miners where he found some small air compressors running on petrol being used by the more affluent small scale miners for underground ventilation purposes.

3.3.13. Ministry of Agriculture, Food Security and Co-operatives

Since the majority of Tanzanians live and work in rural areas mainly in Agriculture, PV activities under other ministries (e.g. ICT) impinge on their life as well. In addition there are strictly agricultural PV applications as follows:

- **PV in irrigation projects:** PV powered irrigation projects bring great possibilities for turning arid land into green areas, enhancing food and cash crop production and thereby improving the economic welfare of the people. The award winning case of PV powered drip irrigation, in Kalale Benin, can serve as an example applicable to Tanzania as well. According to a report of the Solar Electric Fund (SELF) in Kalale District, Benin, in collaboration with a local NGO, *“L’Association pour le Développement Economique, Social et Culturel de Kalalé”*, is organised as summarized in the diagram in Fig 3.7

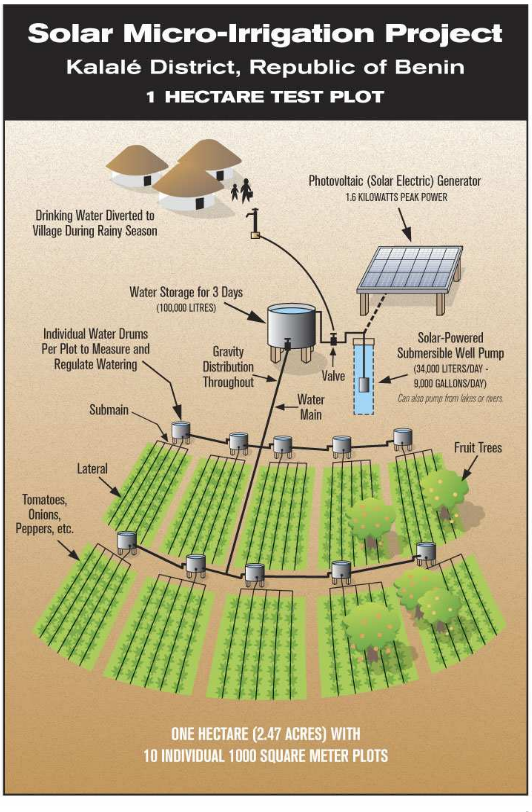

Fig. 3.7: A schematic representation of PV powered drip irrigation at Kalalé (Benin) [26]

- **PV powered irrigation in Energy plants cultivation:** As said in other sections, it sometimes makes more economic sense to use PV in hybrid systems rather than in stand-alone solutions. In some of these solutions green fuels from energy plants (**biofuels**) are more preferred rather rather than fossil fuels. In such solutions **pure plant oils** (PPO), (eg Jatropha oil) may be used instead of diesel, or in some other systems **ethanol** from starch or sugar from plants (e.g. sugar cane), may be mixed with petrol for running small genera-

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[26] SELF website: http://www.self.org/benin_solar_irrigation_project.asp

tion plants and for transport vehicles. According to *Hongo and De Kayser (2005)*, some studies (e.g. *International Energy Agency (2004)*), show that by 2050 biofuels could constitute 50% of transport fuels used by then. These plant based fuels may also be a more profitable energy commodity for local trade and export. In addition to generating employment and income for the farmers (thereby helping fight poverty) the environment is thereby saved by minimising emissions of Green House Gasses (GHG) as the plants are carbon-neutral. But this business requires land and proper management. According to *Hongo and De Kayser (2005)* in the partners for Africa newsletter (2005) only 5 mil. Ha of Tanzanias' 18 mil. Ha arable land is currently in use, of which 0.3 Ha is enough to cater for Tanzania's current energy needs [27].

- **PV in refrigerated food storage and transport:** As is well known, some foodstuffs (e.g. vegetables, fish and meat) are perishable and must, therefore, be delivered to the consumers as fast as possible and be protected from deterioration during transport and also during storage at the initial, intermediate and final delivery sites. Cold storage is one way of ensuring against food deterioration. In places without adequate supply of mains electricity PV may be necessary to run the necessary refrigeration systems during transport and storage.

- **PV powered aviation for agricultural research and pest (e.g. locust) monitoring:** Small unmanned PV powered flying vehicles can be used in agricultural research and pest monitoring.Fig.3.8 shows an example of such a vehicle, which though originally developed for space, (planetary exploration on Mars and Venus), *Landis et al (2001)* such PV powered, light and remote controlled aircraft, can be successfully used in tropical agriculture to carry out unmanned aerial surveys for special purposes.

Fig. 3.8: An artists representation of a small unmanned PV powered aircraft that can be used for special missions (e.g. locust spraying in agriculture)

- **PV Power in Agricultural and Crop development research:** PV can play a big role in powering not only lighting in rural based research labs and offices but the research tools and equipment as well. Seen in Fig. 3.9 (a) and (b) hereunder is a rural based research lab as contrasted to the real life farmers in whose area the research may be taking place. The two photos appear on the same document indicating "….Research on a new edible vegetable oil seed from the *Allanblackia* tree, native of tropical rain forests (sponsored by Unilever Co. through a global partnership called Novella Africa and the World Agroforectry Center in Nairobi, Kenya)".

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[27] http://www.partners4africa.org/docs/PartnersForAfricaNewsletter-May2005.pdf.

Fig. 3.9: Scientific workers at the crop research center and farmers examining a newly researched crop (Allanblakia pods) [28]

3.3.14. Ministry of Defence and National service

- **PV applications in and National Service camps**: In the military, PV technology is of immense importance, especially in field conditions in locations without available power and for tactical reasons where noise from ordinary fossil fuel generators is undesirable. As stated in activities of other ministries above, PV can provide affordable lighting, charge cellphones and power radio and TV broadcast reception as well as power computers for administration and training activities in remotely located camps both for the officers and/or rank and file soldiers and their families living with them in these encampments. However, since most National Service Camps also include production units, in which heavy machinery may be used, then on financial grounds, PV-(Bio-)diesel Hybrid Systems would be better in these circumstances than either stand-alone PV solutions. The exact requirement for domestic and office applications are not different from other buildings of the same nature elsewhere.
- **PV applivations in military barracks and staff residential buildings:** Just as in the case of National Service camps PV may be used in staff residential quarters commonly known as barracks. According to an article by *Thadeus (2007)***,** the Government of Tanzania is implementing a “back-to barracks” campaign in which the government is to build many residential quarters in order to house military officers and their families, currently resident in civilian areas. This offers an opportunity to implement a sustainable living program in which energy efficient buildings integrating PV could be designed and built, both for economic and demonstration purposes.
- **PV application in field-craft activities**. PV can be an important tool in powering residential quarters, office administration and operational communication for soldiers in remote places. PV power for military field hospitals is an obvious case, but this element is dealt with in health services provision under the ministry of health. Similarly PV powered academic training for soldiers in matters not specifically military, is also covered under in similar heading under the ministries responsible for basic education and vocational training as well as higher education and research. Basic health keeping, basic education and adult education for soldiers and non military members of their families plays a very important role for any effective army service. Even more important is the potential role of PV in charging batteries for portable military communication, ordnance survey and other appliances necessary for good planning and execution of successful military operations.

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[28] http://www.worldagroforestry.org/downloads/AF%20in%20Action/1%20A%20magic%20 recipe.pdf

- **PV powered ICT based distance military training:** The importance of distance learning using ICT (e-learning) for defence and security was discussed at a congress in 2006 (Online Educa Berlin, 2006). Such online courses could benefit greatly from PV application. The following points were on the training agenda:
    - Military and naval applications of e-learning
    - Security applications of e-learning
    - E-Learning and security awareness
    - Emergency planning and e-learning
    - Online training for resilience and recovery
    - The business case for e-learning in defence and security
    - Developing and marketing e-learning to the military and security establishment
    - E-Learning and security cooperation
    - Public / private sector cooperation
    - Measuring success
    - Network-centric warfare and e-learning
    - Online training for crisis management
    - Data, information and financial security
    - Public internet security awareness – case studies of the UK and Finland
    - Procurement, contracting and standards
    - Securing applications
    - Language, security and e-learning
    - Major events and online training

3.3.15. Ministry of Labour, Employment and Youth Development

The employment generation potential of PV: The PV industry has great potential for employment creation and, therefore, poverty eradication (alleviation) both directly and indirectly. Some of the direct and indirect job markets that can be created by through the PV industry are as enumerated hereunder:

- Employment in PV product manufacturing, installation and maintenance
- Employment in PV powered fishing, fish storage and transport activities (for further information on PV powered refrigerated transport, see the PV refrigerated transport truck project, by Prof. Bahaj of Southampton University, UK [[29]].
- Employment in PV powered production activities, eg. Tailoring using PV powered sewing machines, painting and related repair work using PV powered compressors, etc.
- Employment in the services industry e.g. PV powered entertainment, (cinema, video shows, TV shows, disco, etc. in remote villages), hotel lighting, commercial internet facilities, battery charging, and nighttimes extended shop keeping.
- The potential of PV in enabling Tanzania and the East African Region to exploit the “off-shoring” job market for ICT intensive jobs is not yet fully exploited. See market analysis for such jobs at [[30]].

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[29] http://www.civil.soton.ac.uk/research/researchdivs.asp?ResearchGrantID=275

3.3.16. Ministry of Information, Culture and Sports

PV can help in powering the above mentioned services for public information, entertainment and educational purposes. Powering of radios and TV broadcasting reception in rural and underprivileged urban communities is necessary so that information programs broadcast under this ministry's auspices reach its destination target. Without a sure power supply for the listeners and viewers, then the broadcasting effort will be wasted because the information will not reach an adequate number of the target population. The rural population without electricity supply does not enjoy the cultural activities and festivities such as cinema, theatre etc that are usually taken for granted in electrified towns. PV powered cultural centers and libraries could help uplift the intellectual life of rural dwellers by offering them live entertainment and increase their options for knowledge gain. At the same time, this effort of improvement of the quality of rural life could have a side effect of stemming the rural-urban migration tide that is currently taking place in all underdeveloped tropical countries, because it will help bridge the rural-urban divide. In other words, ordinary people will be able to get the same or equivalent facilities irrespective of their rural/urban location and in addition, rural dwellers will get the advantage of being able to grow their own food and live healthy lives while enjoying similar cultural facilities as their urban brethren.

3.3.17. Ministry of Water

It is known from personal experiences that piped water is a "scarce commodity" both in towns and rural areas. There are many problems leading to this situation and certainly one of them is "power supply". Under normal conditions, energy availability for water pumping has always been a big problem especially in rural areas. However, in recent years this problem is now aggravated by the general lack of grid power resulting in power rationing even at the big pumping stations. PV along with wind energy could are among the most environment friendly methods of powering water supply that can easily be harnessed in tropical developing countries including Tanzania. Wind is highly location specific. On the other hand PV is one of the possible solutions to the water supply problem that has good prospects because of the sunshine that is abundant in almost all tropical areas. As has been amply demonstrated by the KIUMA project at Matemanga in Tunduru district, Southern Tanzania, PV powers a well which supplies water for the whole center. More details about this aspect of the project are given in the appropriate case study. Another example is the Nigerian irrigation scheme described under Agriculture.

- **PV powered water supply projects in Tanzania:** The water supply situation in Tanzania leaves a lot to be desired. Available data show that in the year 2000 only 68% of Tanzanians had access to safe water. Only 41% of rural dwellers and 54% of urban dwellers had improved sanitation. *(Globalis 2000)* These data, however, speak of availability, access and sources in general terms and do not describe methods by which the water availability is accessed by the consumer from the sources, or the convenience with which water is obtained. As reported from another section of the same statistical database [31]: the UNFPA's "State of the World Population" report for 2003, defines the indicator called "Access to safe water" as "… the percentage of the population with access to an adequate amount of safe drinking water located within a convenient distance from the user's dwelling". It goes on to elaborate thus:. **"Convenient distance" is subject to individual country-level definitions** [this author's own emphasis] but nevertheless goes on to rank Tanzania in terms of this indicator as the 26th country from the bottom on a worldwide scale. Then it goes on to state the importance of this development indicator in the following statement: "The indicator is related to exposure to health risks, including those resulting from improper sanitation".

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[30] http://www.oecd.org/dataoecd/35/11/34682317.pdf

[31] http://globalis.gvu.unu.edu/indicator.cfm?IndicatorID=147&country=TZ#rowTZ

- **PV powered cellular phones for water resource monitoring and data transmission**: **The Bangladeshi example:** PV powered cell-phone technology may be used by the government Tanzania, (or its relevant executive agency) to conduct research on water resources such as monitoring water quality at various remote water sources, just as it has been demonstrated in Bangladesh by the **Earth Institute of Columbia University** under the "**Earth Clinic**" program [[32]]. Over the last several years, an Earth Institute research team and its Bangladeshi partners dramatically reduced the exposure to arsenic of about 70,000 people by testing their wells for arsenic, providing health education, encouraging them to share existing safe wells and by installing deep, safe community wells in fifty villages. Using Earth Clinic funds, the research team will implement a more efficient method of **targeting safe aquifers by using cell phones coupled to GPS receivers to download relevant information from a large available data set and to continuously update this data set with new field observations**. Through this project, the research team hopes to contribute to a national strategy that addresses the arsenic crisis throughout Bangladesh. This example may be used in other countries in similar situation such as some parts of Tanzania. It goes without saying that in remote places without conventional infrastructure such as electric grid and land-line telephony, PV is the most obvious method for charging cellphone batteries. K.B.

3.3.18. Ministry of Lands, Housing and Human Settlements development

- **PV use in human settlements (both Urban & Rural development)** Some examples of PV as used in human settlements are described in more details in case studies for schools and health facilities under staff residential facilities. The approximate electric energy demand for the whole of Tanzania is simply a multiple of an individual house's electricity demand and the number of individual units for the whole of Tanzania (excluding the residential electricity demand already accounted for under the respective ministries i.e. primary schools and primary health care centers opr dispensaries)
- **PV powered ICT in land and settlements administration systems:** The Ministries responsible for land and human settlements administration, and its lower instances both rural and urban areas have a lot of administrative activities, such as land registration, land rights administration, property registration and taxation, as well as land laws enforcement systems. In many countries, most of these activities are being computerized and interconnected thereby establishing a Computerised Land Information and Management System (CLIMS). Tanzania is not far behind. According to *Keasi (2007)* the government of Tanzania, with some help from UN-Habitat and the City of Moscow, is installing an Integrated Land Management System similar to the CLIMS described above which is aimed at informing both government officials and foreign investors about land and human settlement matters. However the rural populations who actually own and use the land but have no electricity, have been forgotten. These people cannot access the information unless they are able to get themselves "connected" on line. Similarly, without reliable electricity, government officials at lower instances of administration, who are usually stationed in these areas without reliable power supply (or no power at all) or senior officers on site visits and inspections in unconnected areas cannot access the necessary site data from their main database for verification purposes, because they would have no power. On the other hand, given availability of PV power at any remote site, the picture changes drastically. It now becomes possible to get land and settlement information anywhere and immediately upon demand. This greatly simplifies administrative work and helps fight corruption as well by elimination of technical "loopholes for corruption" (or, more politely, corruption opportunities). Land administration and distribution processes have

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[32] http://www.earthinstitute.columbia.edu/news/2004/story11-01-04c.html

been cited in some government reports as having many loopholes for corruption *(mianya ya rushwa). (Nyalali, Warioba, Shivji)*

- **PV powered street lighting in remote settlements**: One of the main aspects in enhancing the quality of life in human settlement is the security of the people and their properties. One way of providing such security is provision of adequate street lighting at night as a public service in order to deter crime. In this aspect, PV offers unique possibilities as it can run for a long time with minimal human intervention. An example of PV installation in street lighting is already installed in a project in Sri-Lanka as part of a relief operation after the Tsunami catastrophe of December 2005. Some project information about those activities may be obtained under [[33]]. In that project, a high pressure sodium discharge lamp is used. The solar street light (going under the acronym SSL 440) uses is powered through SOX-E technology the supplying 110V AC through an inverter from 8 x 12V batteries with 120 Ah total capacity, fed by 8 x 55Wp polycrystalline PV modules. A complete sheet of technical properties for a similar the street light system is described under [[34]]:

3.3.19. Ministry of Community development, Gender and Children

- **The impact of PV utilisation in reduction of gender driven inequalities**: In many traditional societies in Tanzania, there are gender and age distributed roles in which certain activities are assigned to individuals according to their ages and/or genders. For example fetching water, firewood and cooking are roles of females in many traditional societies, while in some pastoral societies herding goats is a role assigned to children. On moving towards modern social organisation in such societies, traditional gender and age assigned roles are carried along, thereby hindering effective modernisation of the societies concerned. For example, women would spend a big part of their daytime looking for water or attending to other domestic chores instead of engaging themselves in financially productive activities. In other cases, some children may fail to regularly attend school or may even sometimes fail to/ be prevented from going to school altogether because of their traditionally assigned duty to tend goats. Availability of technology that eliminates the necessity, alleviates the gravity of such duties or speeds up the traditionally long work, may go a long way towards liberating these traditional role-captive women or children and empowering them to be able to engage in other activities in line with the demands of a modern society such as engagement in financially productive activities for women (this liberating them and their families from poverty) or enhancing the ability of a child to regularly attend school, thereby equipping him/her for a more active role in society in future. A case in mind is water supply. If a PV powered water supply system is installed in a village I,t therefore, liberates all the women of that village from the torture of a daylong search for water and gives them opportunity to engage in other financially productive activities. A PV powered goat fence may liberate a child from the necessity of hearding the animals all day long, thus liberating him/her for school.
- **The impact of PV utilisation on child welfare:** The impact of PV utilisation on child welfare (especially immunisation, mother and child health management and children’s education, with special attention on female children’s education) is well elaborated under the activities of respective ministries (i.e. health and education)

3.3.20. Ministry of Natural Resources and Tourism

The role of PV in enhancing the tourist industry can be summarised as follows:

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[33] http://www.robertlipinski.com/projectSriLanka.html

[34] http://www.robertlipinski.com/pdffiles/productflyerSSL400SOX250W.pdf

- **PV in off-grid tourist centres:** PV may be used in off-grid tourist centres for various purposes and activities that need electricity. Such activities include lighting, refrigeration, powering of various ICT items small communication devices i.e. mobile and fixed telephony, computers and the Internet both for tourists, centre administration office work, as well as catering for personal needs of centre workers and their families.
- **PV powered wildlife control and monitoring:** PV may provide power for wildlife control fencing and stationary wildlife monitoring equipment. It may also be used to charge batteries for mobile equipment. PV may be used for powering water pumps at wildlife watering points in remote areas in national parks and game reserves. Venus type PV aviation equipment such as those described under Agriculture may also be used for wildlife monitoring and tracking. PV charged batteries may be used to power animal born marking & tracking devices

3.3.21. Ministry of Finance

- **(Micro-) Financing systems for local PV market development:** PV installations, are relatively capital intensive, because of the initial capital requirement for purchase and installation of the gadgets, although there may not be big “running costs” after this initial investment. This is one of the major obstacles to widespread development of PV in developing countries. It is the so called “Initial Capital Investment Barrier” (ICIB). For this reason, commercial banks may have a big business opening, in lending this initial investment capital to prospective PV system owners. However, most banks either lack the necessary knowledge of PV (and other renewable energy matters) or lack the political will to take this opportunity to make their profits through lending money to prospective PV installers. Some banks argue that the business venture is too risky because of the relative “poverty” of private individuals who are usually targeted by the existing PV marketing systems. The Governments, through their ministries of finance, could help a lot if they could offer credit guarantees for PV installations for the various targeted people and institutions. In the case of Tanzania, initial contacts have already been made by the Tanzania Solar Energy Association (TASEA) and various banks, but there is still no firm commitment yet. Banks need not fear “the poor person’s inability to pay”. Their “inability” is usually overcome by their “willingness” to pay as a form of investment for a better future. Some examples can be taken from the Grameen-Shakti Project in Bangladesh, in which the Grameen Bank lends money to poor people for various projects including PV installations through the Grameen Energy sub-project. The Grameen Shakti project facilitates Microfinancing, Installation, customer training, product guaranty and Service guaranty for Solar Home Systems (SHS). More information about the Grameen Shakti, Finscope and other Microfinace project may be obtained in the annex.

Fig. 3 10: The Grameen funded PV installation in Bangladesh [[35]].

- **Financial and economic policy measures to enhance PV utilization:** The Government needs to be involved in financing PV and other projects in which PV plays a role. Quite unfortunately, however, the Tanzanian financial sector is still apprehensive of lending money to people and institutions for such projects. There is a need for Government leadership in encouraging the banking system to comply.
- **Utilisation of PV in the Tanzanian banking and microfinance systems:** The Tanzanian banking and microfinance system may themselves use PV to power their operations in remote rural areas and un-electrified urban areas such as slums and informal work places (*jua-kali*) where the urban poor live and work. They constitute a sizeable chunk of the financial market that needs looking into.

3.3.22. Ministry of Foreign Affairs and International co-operation

Cooperation between Tanzania and other countries in PV development and provision programs: The Tanzanian ministry of foreign affairs, in the framework of its usual operations can do a lot to foster good commercial environment as well as academic, industrial and research co-operation with many foreign countries in the field of PV and other renewable energy matters. In addition, PV powered boarder posts with not East African Community neighbours can play a big role in enhancing regional co-operation.

3.3.23. Ministry of East African Cooperation

PV at intra-EA boarder posts, enhancing in regional co-operation: PV installations were observed at Namanga and Mutukula border crossing stations. These installations are vital in provision of power supply for office work, office lighting at night. Further expansion of these installations could cater for other life supporting services for boarder staff and their families. The roles of PV in such circumstances could be as enumerated under respective ministries, e.g. health, education etc.

Enhancing and Facilitating Regional cooperation and trade in PV related products and services: PV market development activities are currently going on in all East African countries. However, these activities are at different stages of development in different countries. There is a need for cooperation and coordination of efforts in this activity area just as in other areas. This ministry could play a big role in the streamlining of policies and other activities in this region related to PV and/or the energy sector as whole. Such policies could favour regional trade in PV related products and services as well.

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[35] http://www.microenergy-international.de

3.3.24. Non ministerial Government Offices e.g. Attorney-General’s Office

Development of PV friendly legislation: The Tanzanian Energy Policy document mentions very briefly about renewable energy resources and PV in particular. However, this policy is yet to be implemented in form of specific laws governing this sector. The attorney general’s office could facilitate in the development of such renewable energy and PV specific laws.

Government (and Intergovernmental) Autonomous agencies with PV installation:

- Tanzania Telecommunications Corporation (TTCL)
- Tanzania Railways Corporation (TRC)
- Tanzania Zambia Railway authority (TAZARA)

Other Autonomous Government Agencies with activities impacting on PV in Tanzania includes the following:

- Tanzania Postal Services Company (TPSC)
- Tanzania Bureau of Standards (TBS)
- Tanzania Weights and Measures Authority, (the Tanzanian Government office that in part performs functions equivalent of the German TUEV)
- Tanzania Meteorological Authority
- National Environmental Management Council (NEMC)
- Energy and Water Utilities Regulatory Agency (EWURA)

Summary of Chapter 4: Selected case studies for the most visible public services, namely: Education, Health & Public Administration: Using statistical calculation of demand and supply by PV, this chapter presents an in depth analysis of electricity requirements in the necessary activities for adequate provision of the above mentioned selected public services. In each case a typical small unit e.g. rural school, dispensary or public administration office, is analysed and a PV supply solutions is worked out, then the result is extrapolated for the whole country based on the available statistical information.

4. SPECIAL CASE STUDIES: EDUCATION, HEALTH and PUBLIC ADMINISTRATION

After the general ministerial roundup in the preceding chapter, in which the potential for PV utilization in government services was discussed, in this chapter we discuss in more details the potential for application of PV in special public service sectors, namely Education, Heath, and Public administration on case study basis. These three fields have been selected because they are sectors that are more directly felt by most people. A more detailed presentation of this analysis follows hereunder:

4.1. SPECIAL CASE No.1: EDUCATION

4.1.1. Introduction to the Tanzanian Educational System

The formal education system in Tanzania is organised in one main stream with several branching-off parallel streams as follows:

- **Preschool**, to which children may be admitted around the age of five, are not obligatory. Although there are government directives concerning them, preschools are not state controlled. Each school is allowed to follow their own syllabus.
- **Primary School**, lasting for 7 years is the first officially mandated educational stage and is nominally obligatory for all children 7 years old and above. Primary education ends with a nationally administered Primary School leaving examination, on which selection to the next educational phase, the Secondary school, is based.
- **Secondary School follows** immediately after primary school and runs in two consequent stages:
    - Ordinary level (O-Level) Secondary school (4 years) and
    - Advanced level (A-Level) secondary school (High school (2 years)),

- **University Education**, starts after the A-level and is offered on international standards with:
    - Bachelors degrees,
    - Masters degrees and
    - PhDs and other research degrees.

In addition to this mainline direct education system, there is also:

- **Vocational Training and Education:** These are formal sub-professional and semi-professional job training institutions for artisans, technicians and other personnel to which a person may go either after primary or secondary school depending on the complexity of the job in question.

Other non University professional and semi professional Education Institutions (colleges and institutes) offering various programs at the end of which graduates obtain certificates, Diplomas, Advanced Diplomas, depending on their level of entry and duration of studies. Many of these colleges, however are not administered under the ministries responsible for education and Vocational training, or Higher Education, science and technology, but administered under other ministries or by professional organisations according to their line specializations. Such institutions include the following:

- Teacher Training Colleges
- Nurse Training colleges
- Medical Training Colleges
- Agricultural Training Colleges
- Wildlife Training Colleges
- Colleges of Accountancy
- Police Colleges
- Military Training Academies

As a rule of thumb, vocational schools take their students after primary school for courses ranging from 3 months to 3 years, and graduates obtain certificates differentiated or graded according to duration and content of courses. Colleges also take students from O-level secondary schools offer certificates after 2 or three years training, while those that take students after A-levels give (ordinary) diplomas after 2 year courses and advanced diplomas after 3 year courses. Under the current system, however, these courses (college certificates and diplomas), however are not adequately recognised by the university systems, and therefore do not generally qualify their holders as direct university entrance qualifications but serve only as added advantages.

Fig. 4.1: Traditional schooling (left) and modern schooling using ICT (right)

PV application is a key enabler for successful use of Information & Communication Technology (ICT) and can thereby revolutionize the teaching-&-learning experience in tropical developing countries from the early beginnings.

4.1.2. The Current Tanzanian Education picture

By the end of 2002 the education picture in Tanzania was summarized as follows:

According to a study report by ILO-IPEC and the then Tanzanian Ministry of Labour, Youth Development and Sports *(ILO-IPEC 2003)* in the year 2000/01 there were 11,965,146 children of ages between 5 – 17 years in Tanzania, of which only about a half, i.e. 6,802,951, were going to school. That represented a national average of only 56.9 % of all children of that age group in that year. However, in rural areas, where about 70% of the population lives, the ratio is even lower, i.e. 53.1%. On educational facilities, according to a different report by Joseph Mungai, *(Mungai 2000)* the then Minister for Education, in the year 2000 Tanzania had 11,654 primary schools and 927 secondary schools.

Since then, primary school enrolment figures have changed for the better but not so much for secondary and higher education. According to the latest available data, from the Basic Educational Statistics (BEST) 2003-2007 issued in June 2007, the school demographics were as follows: The total primary school enrolment in 2007 standard I-VII (ages 7-14) was 8,316,925 with a gender distribution of 4,215171 boys and 4101754 girls, an overwhelming majority of whom were enrolled in government supported primary schools. Interestingly, a number of non-government primary schools had meanwhile sprung up, taking a very small minority of young learners (about 0.1%). The distribution of people in pre-university education was 7.8% in Preschool, 81.9% in Primary schools and 10.1% in Secondary schools. However, only 0.2% were in Teacher Training Colleges (TTC).

The official standard for space requirement for students in Tanzania is around 45 students per classroom in primary schools and 30 students per classroom in Secondary schools. Although due to lack of facilities this standard is never followed, we use this guideline to estimate an average classroom to have at least 40 students, thereby arriving at a conclusion that these students would require at least **170,074** classrooms.

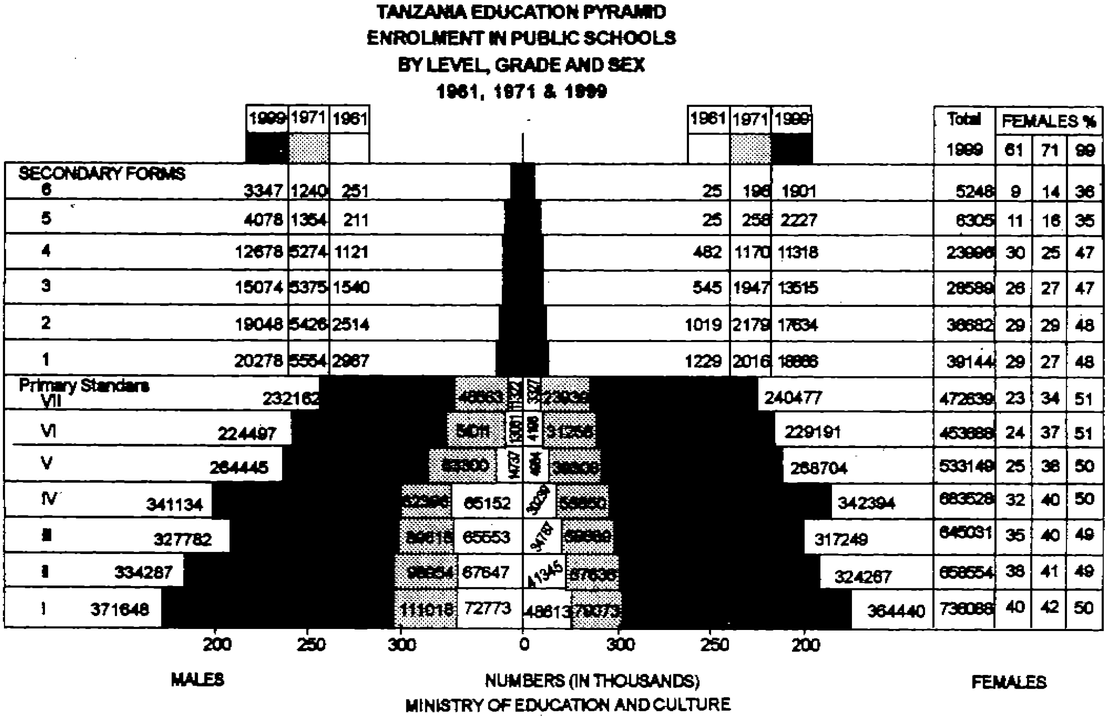

Fig. 4.2: Primary and Secondary school enrolment in Tanzania, 1961, 1977, 1999 ***(MOEC, 2000)***

Other statistical data on education from the Ministry of Education up to 1999 as obtained from [36], indicate milestones achieved in enhancing enrolment and gender balancing in primary education. The following graphic representation of the educational pyramid from the same site (accessed 11. Dec. 2006) shows that great efforts have been made to promote education and gender balancing in education.

4.1.3. Energy in the Tanzanian Educational system

Energy in schools in Tanzania is used mainly for cooking, powering of mechanical devices such as transport machines, pumps etc as well as lighting at night but most of this energy is not electricity. . However, electricity is preferable for night lighting, and absolutely necessary for running electronic equipment such as radios, TV, computers and their peripherals and networks, and other teaching and learning aides. It is also used in refrigeration and air conditioning but devices for such purposes are rarely used in Tanzanian schools. In some cases, especially in post-secondary colleges and higher learning institutions in cities, air conditioning may be seen to be used mainly as a status symbol rather than a means of satisfying real human comfort needs, although such needs may actually exist in warm-humid places such as Dar es Salaam.

As one move higher up the education ladder, schools become more rare, distances from home to schools increase and therefore the need for and provision of boarding facilities becomes relatively greater. Currently, although the government is trying hard to promote construction of more day secondary schools near children's homes, but a combination of factors such as availability of qualified staff and other amenities, still hinder this progress and, in contrast, encourage more intense utilisation of existing resources, thereby generating more requirement for boarding facilities at/near existing /old post-primary learning institutions such as secondary schools, vocational training centers and other colleges. This, in turn, creates conditions for a more intense demand on energy, including electricity in those centers.

4.1.4. Electricity demand in Primary schools

Along with lighting in boarding schools, the most important use of electricity in schools will be the powering Information and Communication Technology (ICT) hardware i.e. computers, their peripherals and networking hardware as well as other teaching/learning aides. Computers (either standing alone or, better still, networked) can also be used for administrative purposes both in schools and related government offices at regional and district levels. Availability of the Internet in our school systems can revolutionize education by giving students and staff an extra resource for obtaining, storing and transmitting information, for teaching and learning. The importance of computer networking, recently underscored by some knowledgeable Tanzanian entrepreneurs, Ali **Mufuruki** and Ami **Mpungwe,** when they said, among other things, "Gone are the days of individual computers"

Fig. 4.3: Various models of the XO computer from the OLPC project

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[36] http://www.tzonline.org/pdf/basicstatisticineducation.pdf

We see various projects sprouting up at national but mostly at international levels, e.g. [37]. Realising the importance of ICT in modern education, the Media Labs of Massachussets Institute of Technology (MIT) in the USA, have launched the One Laptop Per Child (OLPC) program which has developed especially cheap laptops for children in underdeveloped countries, which specifically designed to be affordable and rugged so that children in target countries can use them both at school and at home. Special design (e.g. no hard dick) and production location and scale (Shanghai, China) have contributed to make them relatively cheap at US$100.00 per piece ac compared to the current US$ 1000.00 per piece for other laptop with comparable performance. (However in a country with many people living less than US$ 1.00 a day, this price is still difficult for many parents). In the top photograph, the power supply problem was addressed by introducing an internal hand wound generator. However, the question of power supply for ICT is not being fully addressed. PV has a great role to play as a power supply option both at individual PV level and in powering computer networks and local Internet station. ICT as a tool in Education and ICT Education itself are nowadays much in vogue.

4.1.5. PV as an Electric Energy source for Education in Tanzania

The points of activity and research on the role of Photovoltaics in the Tanzanian educational system may be summarized as follows:

- PV powered ICT in Education, actual situation and potential
- PV in other aspects of the Education system (eg Education administration)
- Training of PV specialists (installation and maintenance technicians)

It is to be noted that with proper **daylighting** design, no artificial (electric or otherwise) lighting is required in Tanzanian classrooms during daytime hours. Currently most primary schools in Tanzania are **“day schools”** so they generally do not need any electricity for lighting purposes. However, there are a few **“boarding schools”** in this group, mainly organised by missionaries and other volunteer services to take care of education of **“children with special needs”** such as **with physical and/or mental handicaps**, or whose parents cannot keep them at home for various reasons. Children benefiting from this arrangement include the salvaged former **“street children”,** children in **nomadic** tribal areas and those from relatively well-to-do families whose parents have opted to give special education in so called “English medium schools”, otherwise variously called “academies”, “junior academies” or “international schools”, but such schools are not commonly available in many places. These do need lighting at night.

In future, more lighting will have to be instituted in many rural primary schools. It is the contention of this researcher, that in the effort to raise education standards in Tanzania, one of the hurdles, namely provision of adequate **teaching and learning space**, would be overcome by **more intensive utilisation of the existing buildings**, not by cramming more students in the few classrooms during daytime but by extending the time of utilisation of buildings into the night. This can be achieved, for example, by instituting a **two shift schooling system**, whereby the evening shift would have to **study for a few hours more after sunset**. Such a system had already been introduced in urban areas but was scrapped because of safety concerns for students. However, with careful planning and probably reintroduction of boarding facilities in primary schools, this system can be resumed.

It is also possible to use primary school buildings for some hours during the night to offer other forms of education such as **adult education** and **distant learning** or even village entertainment. Thus the degree of utilisation of the existing classroom buildings stock can be greatly enhanced if nightime utility were to be installed. In the simplest terms, this would involve night lighting of the classrooms. Given the tropical conditions prevailing in Tanzania, night lighting is easily achievable using Photovoltaics.

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[37] www.laptop.org

Besides the traditional application of lighting, the most important application of PV in tropical schools is that of powering **Information and Communication Technology (ICT)** in teaching and learning applications. There are two scenarios in the use of ICT in schools. The first scenario is that a few electronic gadgets are used mainly by teachers in acquisition of information for teaching purposes and/or demonstration to students in which a whole class shares just one gadget operated by one person for others to observe. The second scenario is the hands-on learning method in which each student (or a small group e.g. two persons) works with their own computer. For effective teaching both methods must be used depending on what is being taught. Given other constraints going on in Tanzania, it is not unreasonable to think of an initial phase whereby each school can first have at least one computer, then later each school gets one classroom fully equipped with computers and other facilities for ICT training purposes. In the latter case we are speaking of about 45 computers per school, whereby 41 computers are used by the 40 students in any one class and their teacher, and the remainder are used by other staff members elsewhere in the school. In the interest of maximizing use of resources, such a classroom may be used by students of one class at a time in two hour shifts. It can, therefore serve five different classes of students per day and this means it would be fully occupied for say 10 hours per day. Computers are becoming more energy efficient almost by the day. Currently the most energy efficient group of computers are laptops. In the interest of energy efficiency, laptops are hereby recommended for use in solar PV powered tropical classroom. With this scenario in mind energy requirement for a typical school are presented following calculations.

4.1.6. Calculation of PV requirements for a single primary school

According to this author's estimates, a typical classroom able to comfortably house about 40 students will have approximately 40 m^2 floor area, which is sufficient to house not only students and their teacher but a few teaching and learning aids as well. From thence the energy calculations will be based

a) Power for ICT in a single primary school.

Bearing in mind the fact that the main demand for electricity in primary schools in tropical countries such as Tanzanian is driven by ICT it is important to consider the main target of deploying PV in primary school as being the need to power ICT. From the foregoing section, it is assumed that only one classroom is a specialised computer laboratory equipped with 41 laptops and that another 4 laptops are used in the school for administrative and teaching preparation activities making 45 computers working 10 hours per day. Assuming a fully connected (with peripherals and network gadgets) consumes a power of about 100W, the total power demand for ICT in a school will be 4500W and the daily electric energy demand will be 45000Wh/day. Besides the occasional need to charge a cellphone, there is no other demand for electricity during daytime hours. This indicates that the best option for powering ICT in most rural primary school is stand-alone PV.

From *Hankins (1995)* it is known that many places in Africa experience a daily solar harvest of between 4.5 and 6.5 peak hours (h_p) (=4.5kWh/m²/day) and for fail-safe stand-alone PV, the best practice to assume the worst conditions of 4.5 peak hours per day. With such an insolation, a demand of 4500 Wh/day will be covered by 45000Wh/4.5h_p = 10000W_p of PV modules. This implies a requirement 100PV modules @100Wp. (Alternatively, for ease of transport and delivery to site, manual un-mechanised installation, and availability in local market conditions, a lower PV module wattage rating may be selected with a corresponding increase in the number of modules. For example 200 PV modules@50W_p)

In addition to the modules, batteries are required for storage of electricity and stabilisation of the supply. Although batteries are described in more details in chapter 2 of this thesis, for purposes of storage capacity estimation, some reasonable assumptions must be stated here. With batteries a 12V or 24V DC system voltage may be selected. Battery types differentiated by depth of discharge (DOD) among other parameters may be selected depending on availability in local markets, costs or other logistical considerations. In general, the required battery capacity is calculated by this formula:

$$Q = \frac{W}{V * \eta}$$

where Q = Required battery storage capacity [Ah]
W = Useable energy storage demand in [Wh]
V = system voltage [V]
η = depth of discharge (% or decimal fraction)

From this formula it can bee seen that the storage capacity is influenced by the depth of discharge. In most current cases of terrestrial PV systems lead-acid batteries are used, of which two major types are most often encountered: either ordinary automotive lead-acid batteries at a 50% allowable depth of discharge (DOD) or specialised deep cycle solar batteries with an 80% DOD. Also worth noting is the fact that there is no need for an extra increment in battery capacity as a safety margin because the system has been calculated on the worst scenario assumptions of a minimum insolation in the worst month. Moreover for a school system, there are extra days with no work at week-ends and public holidays. The Solar gains on these days also contribute to the energy storage margin through charging without discharge.

In the case of the primary school example, therefore, the requisite battery capacity for ICT would be as given in table 4.1 below.

Table 4.1: Required battery storage capacities (in Ah) for required ICT in a single primary school in Tanzania according to battery type and DC system voltages.

Battery type **System Voltage**	**Standard Automotive battery (DOD = 50%)**	**Deep cycle "Solar"battery (DOD = 80%)**
12V DC	7500	4687,5
24V DC	3750	2343,75

This means that for ICT alone, if a 12V DC system voltage is chosen, then each primary school will require 75 automotive batteries @ 100Ah or 47 specialized deep cycle solar batteries. It is worth noting here, that in the case of use of automotive batteries in 24V DC system, the system is achieved by series connection of two standard 12V batteries. This means, therefore, that although the calculated capacity is halved, the actual number of batteries in the 24V system will be the same as in the 12V system if the original number of batteries in the 12V system is even, otherwise it will have to increase by one piece over the required number in a 12V system. Of course the actual capacity will also increase.

The number of batteries may be reduced if higher battery capacities are selected (especially in the case of deep cycle solar batteries). Worth noting, is also the fact that it is possible to obtain 2V "cells" of different capacities for deep cycle specialised solar batteries. Thus users, system integrators or installers may "assemble" batteries of other system voltages and capacities especially if they decide to use inverters so as feed their computers from standard AC voltage. However, due to inverter influence (inverter efficiency =97%) the requisite battery capacity may have to be increased by dividing the DC capacity by 0.97 The possibility of using AC also enables use of modules of higher rated voltages. The main advantage of higher voltage is the possibility minimising energy losses through the "Joule effect" heating thus enabling use of thinner and longer wires, in turn this gives flexibility of building and system design for location of the various components. The only major limitation to battery and module size is the human handling capacity which is dependent on the degree of mechanisation available during system installation or in case of other necessary handling for whatever other reason such as during maintenance or repair after accidents. This should be an important consideration factor in PV installations in rural areas of Third World countries.

b) Power for lighting in a double shift primary school.

As stated earlier, primary schools usually work only during the day. However due to pressure for expansion of the education system as explained above, an evening shift may be introduced. If it is decided that the primary school buildings be used more intensively and an evening shift instituted, then it would be reasonable to increase the school's PV capacity by the increment in energy demand due to the evening shift. . Since the evening shift begins in the after noon it can also be organised that no ICT runs at night so that evening energy demand is for lighting only. With standard illumination using fluorescent lighting, a consumption of **10W/m^2** is acceptable. So a classroom of about **40 m^2** would consume about **400 W** only. Excluding other external factors, an afternoon shift, beginning at about 2:00 pm (14:00 hrs) will be able to have done a reasonable day's work commensurate with that of the morning shift by 10:00 pm (22:00 hrs). Since in tropical areas the sun sets soon after 6:00 pm then it is reasonable to suggest that lighting will be required from 6:00 pm till 10:00 pm. This gives us a reasonable estimate of about 4 hours requirement for classroom lighting per working day. So the energy demand for classroom lighting will be **400W x 4 h/d** = **1600 Wh/d** for each classroom in this program. A typical primary school in Tanzania has about eight rooms of classroom size working at the same time. Therefore the total energy demand for lighting of the classroom area during the evening shift would be given by the following formula:

$$W_l = n * P * t \quad \text{where} \quad \begin{array}{l} W_l = \text{daily lighting energy demand for the school [Wh/day]} \\ P = \text{lighting power demand per classroom} = 400\text{W} \\ \text{n} = \text{number of classrooms for the school} = 8 \\ \text{t} = \text{daily lighting duration } = 4 \text{ h/d} \end{array}$$

Whence W_l = 8*400*4 = 12800 Wh/day

Using the same arguments as for ICT above, we assume a minimum insolation of 4.5 (h_p/d). This means under the worst conditions, satisfying the above mentioned demand in a single primary school we shall require 12800(Wh/day) / 4.5 (h_p/d) = 2844,4W_p which boils down to about 29 PV modules@100Wp.

Battery capacity demand for classroom lighting, estimated in the same way as for ICT gives us the following results:

Table 4.2: Required battery storage capacities (in Ah) for required lighting in a two shift primary school in Tanzania according to battery type and DC system voltages.

Battery type System Voltage	Standard Automotive battery (DOD = 50%)	Deep cycle "Solar"battery (DOD = 80%)
12V DC	2133,33	1333,33
24V DC	1066,67	666,67

This implies that for lighting up a single primary school for 4 hours after sunset using 12V DC systems voltage, one may require either 22 standard automotive batteries (DOD 50%) or 14 deep cycle "solar" batteries (DOD 80%). A 24 V system would cut the mathematical capacity by half but without lowering the number of batteries if unit capacity remains constant. Only their connection system changes. As stated before in the case of standard automotive batteries or 12V packaged deep cycle batteries a 24V system must have an even number of units. If a standard AC system (220-240V, 50 Hz AC) is preferred, then the requisite battery capacity will have to be slightly increased by dividing the DC capacity by 0.97 representing the 97% efficiency of most currently available inverters. Worth noting is the fact that for lighting fitments standard AC appliances are usually cheaper and more readily available on the market than equivalent DC appliances. For large systems, therefore, it may make financial sense to consider investing a little more in battery capacity and inverters in order to use an AC system.

4.1.7. Estimate of PV requirements for primary schools in the whole of Tanzania

From the latest available statistical data (MOEVT 2007) there were 15624 primary schools in Tanzania in 2007. If each school requires 100 PV modules @ 100 Wp and 47 deep cycle solar batteries @ 100 Ah for running ICT then all primary schools in Tanzania would require 1,562,400 such PV modules and 734,328 such batteries for a 12V DC system voltage. If an AC system is preferred then appropriately powered inverters must be introduced the batteries will have to be increased to 757,040.

If a 2 shift schooling system is introduced in all primary schools in Tanzania, then an extra 45096 PV modules and 176,736 deep cycle batteries would be required. Similar to the ICT case, if an AC system is preferred then appropriately powered inverters must be introduced the battery pack will have to be expanded to182,202 units.

It should be noted here that although preferable for all modules and batteries to be similar in both cases, it is not absolutely necessary. This gives room for improved versions to be used if a phased implementation plan is preferred.

4.1.8. Energy demand in Secondary schools

Secondary schools in Tanzania have almost the same energy demand patterns as primary schools, but are slightly more complex. As distinct from primary schools which generally have one stream per class, secondary schools usually have several streams per class, which are usually designated by alphabetical letters A, B, C, D etc. In addition to ordinary classrooms, secondary schools have many specialised buildings such as laboratories, libraries, workshops and administrative buildings. Being fewer and, therefore, further away from students' homes and requiring higher qualification staff who may come from ethnic origins further away than in primary schools, most secondary schools tend to have more boarding facilities for students and dwellings for their staff, that are almost always of a higher standard than in the case of primary schools. For this reason Secondary schools have a higher energy demand per school. This energy demand in secondary schools usually takes care of the following needs: cooking, lighting, air conditioning, water pumping, running electronic information and communication (ICT) devices e.g. computers, TVs, radios, cellphones etc. Among all these needs lighting and ICT needs have a special importance and are the most likely to benefit from PV. In this thesis, therefore, treatment of PV application in Secondary schools focuses on lighting and ICT requirement.

For calculation of electric energy demand in secondary schools, standard plans of some typical secondary schools buildings, supplied by the Tanzanian Ministry of Education and Vocational Training, were used. They are separately presented and attached in the annex. Generally speaking, while the buildings may differ in plan and area, they are typically of the same layout in that they are all elongated in one direction and have a veranda to one side to facilitate movements between different spaces (classrooms, labs etc) within the block without being too much exposed to external elements, mainly rain and direct sunshine.

The typical daily energy consumption pattern of such a secondary school center, is a fairly low base load running ICT during the day, followed by a predictable higher peak load between sunset and about 10:00 p.m. (22:00 hrs) followed by an even lower but constant base load for the rest of the night till morning. Given this electricity demand pattern a **hybrid system** combining PV, diesel generating set and battery storage over a local micro-grid is more appropriate. Ideally, in such a hybrid system PV and battery storage combined with a Diesel generator set modified to run on bio-fuels such as Jatropha Oil, would be more appropriate in many Tanzanian situations and in many tropical developing countries where land can be made available for cultivation of bioenergy plants without jeopardising land availability for land for food growth and other sustainable land uses. Jatropha plant is not new in Africa, but according to *Gehrman (2007)***,** its use as a bio-diesel source has now put it to new use and this fact is raising hope for many Africans.

4.1.9. Electric Energy Demand in Vocational Training Schools, Teacher Training and Higher Education

The electric energy demand pattern in Teacher Training Colleges (TTCs) is similar to that in Secondary schools but only the figures are higher because the students, being of a higher age group and a nominally higher social class, have longer working hours in which they use more energy for lighting and ICT and in some cases more powerful machines are used for both training productive processes. As a stated earlier in the case of secondary schools, a **hybrid system** combining PV with other electricity generating systems is recommended and in ideal conditions a hybrid system comprising of PV and Diesel genset modified to run on biofules such as Jatropha Oil, or wind energy would be appropriate. For purposes of demonstration.

4.1.10. Examples of Hybrid Systems sporting PV with Diesel running on Jatropha Oil

Some good examples of such hybrid systems include the Mbinga Sisters Convent, and the KIUMA Project in Matemanga, both in Ruvuma Region of Southern Tanzania. The KIUMA Project is a multipurpose undertaking incorporating a Hostpital, various schools and community development subprojects, whereas the Mbinga Convent Project runs a girls vocational training school. According to available data, the PV-Jatropha-oil hybrid system at Mbinga has the following parameters:

- Solar generator output capacity: 8.1 kWp
- Modules: 81 Schott Solar ASE 100-GT-FT
- Energy inversion: 3 Sunny Island SI 4248s and 3 Sunny Boy SB 3300s
- Energy storage: 3 OPzS battery units with 800 Ah / 48 V each
- Plant oil generator: 30 kW power unit with Kubota engine and Mecc-Alte generator [[38]]

4.2. SPECIAL CASE No.2: HEALTHCARE

All health care activities in Tanzania are conducted by both government and private (voluntary, religious and commercial) organisations under the auspices and direct supervision of the **Ministry of Health and Social welfare.**

4.2.1. Background information on comparative healthcare budgets between developed and underdeveloped countries

Healthcare provision in Tanzania, is conducted in the framework of the worldwide international healthcare system. According to the *"World Health Report 2007" (WHO 2007)* as illustrated in Fig.4.4 below, Africa (including Tanzania) is disproportionately vulnerable to health risk factors of international concern.

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[38] „Renewable Energy Made in Germany“ (2007): www.german-renewable-energy.com/Renewables/Navigation/Englisch/Biomasse/case-studies,did=183292,render=renderPrint.html

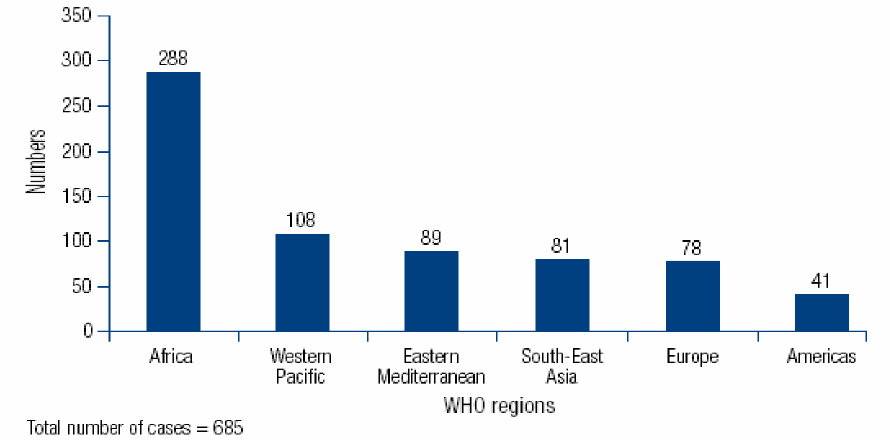

Fig. 4.4: Events of potential international public health concern by WHO region, Sept. 2003 - Sept. 2006

However, at a global scale, we see that there is a great gap in health expenditure between high income industrialised countries and low income developing countries. The annual per capita expenditure on health care in Africa is a fraction of the finances available in the high-income countries. When introducing any technology this huge gap should be considered. For example, according to a European research group on appropriate health care technology for the Third World (HEART), operating from the Netherlands and Germany, the annual healthcare expenditure in industrialised countries of Europe and America is of the order of US$ 1300 per person per annum, as compared to under US$10 per person per annum in sub-Saharan Africa where Tanzania belongs. (Fig. 4.5)

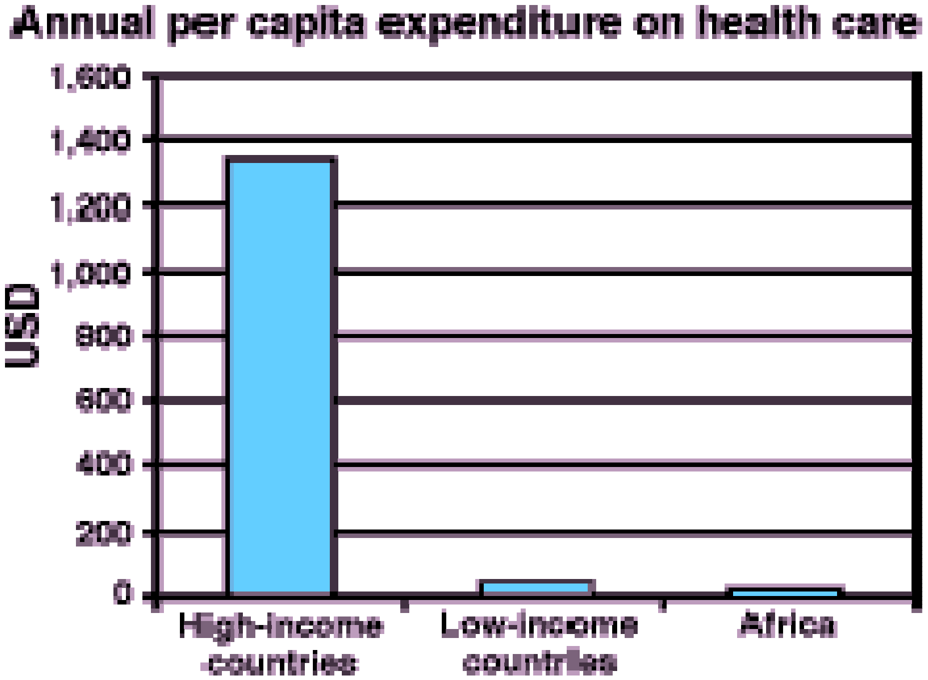

Fig. 4.5: Per capita expenditures on healthcare for Developed and Underdeveloped Countries [39]

This gap, given the fact that over 80% of the world's population live in underdeveloped low income countries is further amplified as summarised in fig. 4.6 .

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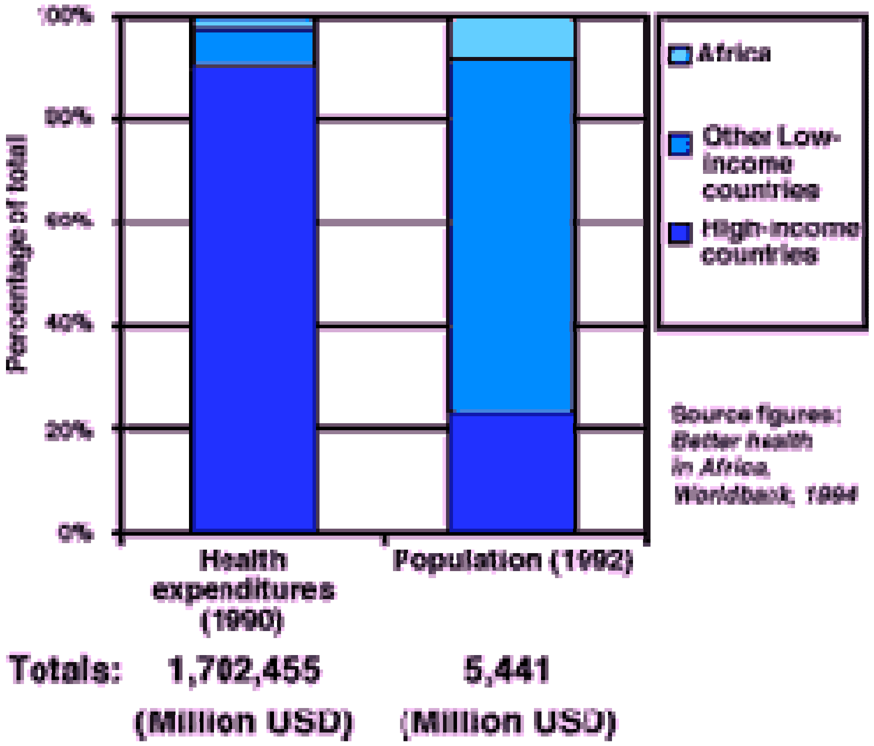
[39] HEalthcare through Appropriate and Reliable Technology (HEART) http://www.heartware.nl/rsrch.html#rsrchgoup



Source figures: Better health in Africa, Worldbank, 1994

Fig. 4.6 Comparison of worldwide health care resources distribution and population distribution

So in order to improve the situation, innovative ways must be found, one of which is to have solar energy, both PV and solar thermal contributing actively in medical care efforts. PV may help in supplying power for some basic medical processes that require electricity as the basic energy input and solar thermal assisting in areas where thermal energy is the required energy input form. The most important areas of health administration that can benefit from PV application are, lighting, medical refrigeration, various diagnostic tools, operative medical telecommunication and health administrative communication. Lighting in healthcare is applicable in various hospital spaces such as consulting rooms, operating theatres, laboratories, patients' wards and health workers' residential houses. Solar thermal energy, on the other hand, may be used in steam production for sterilisation of medical equipment and supplies and similar applications.

4.2.2. Overview of the Healthcare system in Tanzania

Health provision system in Tanzania is organised as pyramid, with a strong focus on rural areas where the majority of the people lives. **Village Heath Posts** are informal community based healthcare organisations with at least two elected villagers providing mainly preventive services after a short training. Then the first formal curative and preventive services are provided at **Dispensaries** which are supposed to take care of between 6,000 and 10,000 people and to supervise all Health Posts in their respective ward. (A **ward**, in this case, is a political administrative unit, two steps below a district). A dispensary is headed by a trained practitioner, the Rural Medical Aide (RMA) helped by one or two trained Grade B nurses and nursing assistants who may or may not have rudimentary basic health training. A dispensary already has specialised buildings and basic medical equipment (some of which may be powered by PV). There are also ambulatory public health and clinical services conducted by **Mother and Child Health (MCH)** units which take special care of expectant and new mothers as well as their children up to the age of 5 years. However, these are not separate institutions but specialised units within dispensaries and other medical care institutions. They are usually staffed by members of their parent organisations. They usually work at different places on especially appointed days according to a preset timetable. After dispensaries come **Health Centers** which are supposed to cater for around 50,000 people each. These are more equipped in terms of personnel and physical infrastructure and equipment. Above Health Centres come **District Hospitals** of which at least one is mandatory for every district. In case of new districts which may not yet have their own Government District Hospitals, agreements are made between the Government and some religious or other voluntary organisations operating a hospital in the district so that such a hospital may be elevated to the rank of a **"Designated District Hospital"** and receive special support in terms of financial subventions and qualified personnel attachments. Both actual and designated District Hospitals must have elaborate physical infrastructure, qualified personnel and equipment. Above District Hospitals come **Regional Hospitals** which are even more equipped in infrastructure, equipment and personnel including specialist medical practitioners and services. Each administrative region is supposed to have a Regional Hospital and when absent (for new regions) such services may be rendered from a nearby regional hospital or through a designated regional hospital as in the case of districts. Above Regional Hospitals come **Referal or Consultant Hospitals** of which currently there are **only four in Tanzania**, two being Government owned and two being from religious organisations but Government supported.

Table 4.3: Tanzania's health services provision physical infrastructure in 2000 [40]

Facility	Agency				
	Govt.	Para-statal	Volunt./ Relig.	Private	Other
Consultancy/Specialized Hospitals	4	2	2	0	-
Regional Hospitals	17	0	0	0	-
District Hospitals	55	0	13	0	-
Other Hospitals	2	6	56	20	2
Health Centres	409	6	48	16	-
Dispensaries	2450	202	612	663	28
Specialized Clinics	75	0	4	22	-
Nursing Homes	0	0	0	6	-
Private Laboratories	18	3	9	184	-

Juntunen (2001) summarizes development of the Tanzanian healthcare system since independence to modern times and gives the latest available statistics as follows:

"At the early stages of the independence in 1961, there were 22 health centres and 875 small, meagrely staffed and equipped dispensaries operated by local authorities. The average number of people served by each dispensary was 11 700. There were about 100 hospitals, 40 of them run by voluntary agencies, such as churches. The physicians, working in the country numbered 415, only 12 of whom were Tanzanians, and there were 380 rural medical aides. Total number of nurses was 1400. (Aarnikko *et al*. 1980, Unicef 1990.) - **The present national health care system includes 8500 village health posts, 3000 MCH clinics, 2644 dispensaries, 260 health centres, 98 district hospitals, 17 regional hospitals and 4 referral hospitals.** (Finnida 1992). The population per health facility is 7500:1 and the statistics show that there is a shortage of trained health care professionals in the country, e.g. population per nursing staff 1000:1 and per physician 23 000:1 (Ministry of Health 1996.). The government health units often face a shortage of trained manpower, inadequate facilities and drugs, and low staff motivation. A user fee

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[40] Ministry of Health Statistical Abstract, as quoted on the ministry's official website: http://www.tanzania.go.tz/health.html

for government hospital services was introduced in 1993. Private health facilities are being established in increasing numbers, especially in urban areas. (Chiduo 1991, Kiwara 1994.) “

As to Medical personnel, table 4.4. provides key data for the year 2002.

Table 4.4: Tanzanias list of medical personnel as of 2002 [41]

Indicator	Quantity
Physicians (number)	822
Physicians (density per 1 000 population)	0.02
Nurses (number)	13,292
Nurses (density per 1 000 population)	0.37
Dentists (number)	267
Dentists (density per 1 000 population)	0.01
Pharmacists (number)	365
Pharmacists (density per 1 000 population)	0.01
Public and environmental health workers (number)	1,831
Public and environmental health workers (density per 1 000 population)	0.05
Lab technicians (number)	1,520
Lab technicians (density per 1 000 population)	0.04
Other health workers (number)	29,722
Other health workers (density per 1 000 population)	0.82
Health management and support workers (number)	689
Health management and support workers (density per 1 000 population)	0.02

4.2.3. PV use in Health Services provision

PV may be used in the healthcare system in various ways such as direct use in hospitals, in healthcare administration offices at various levels (right from the ministry to the lowest primary care unit) and for powering communication among health care facilities, personnel and between healthcare facilities and other public service a agencies.

4.2.4. The smallest unit: Electric energy demand for dispensaries

As seen from the table above and in all the statistical data quoted above, **dispensaries**, being the **smallest units**, professionally equipped that are the most accessible to the people, play an important role in the primary healthcare system of Tanzania and the whole of the East African region. If dispensary services are improved through provision of PV electricity for basic power supply to run such basic facilities, great service will have been rendered to the people.

At present those basic services where PV may play an important role in primary healthcare at dispensaries include the following:

- Night lighting in wards and
- Night lighting in emergency services at night (especially in maternity and delivery facilities)

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[41] World health organisation (WHO) key indicator table http://www3.who.int/whosis/core/core_select_process.cfm?country=tza&indicators=healthpersonnel&intYear_select=all&language=en

- Refrigeration systems for cold chain vaccine and medical supplies storage and transport. (a good sampling of modern medical refrigeration units, some of which can run directly with PV and standard ones that may run on PV through an inverter in between may be found at [[42]])
- Lighting for basic microscopy in small diagnostic medical labs available at these dispensaries.
- Charging of cellphones for occasional communication of medical staff with higher authorise or with peers in neighbouring medical facilities and in other government services.
- Domestic power supply for resident medical staff (mainly for lighting and some home electronics such as radio and TV reception).

In future additional services that my be added to the above mentioned include telemedicine, i.e. computerised information handling and/or audiovisual communication, between individual medical personnel in different medical facilities, geared at solving immediate medical problems without necessarily always resorting to the medical referral procedures which may be financially expensive and time consuming, factors which may mean the difference between life and death of the patient at the worst or unnecessary prolongation or relief of suffering of the patient at the very least.

4.2.5. Actual dispensary case study: Kishanje Dispensary

Because of the importance of dispensaries, energy demand for dispensaries is calculated using the example of **Kishanje dispensary, Bugabo division, Bukoba Rural District, Kagera Region in North–Western Tanzania.**

The physical infrastructure at Kishanje dispensary include the following:

- The main dispensary building with a centrally located outpatient waiting room, flanked by one consulting room on one side and a dispensing cum dressing room on the other. The consulting room also serves as an administration office and documents storage room, while the dispensing room serves as a storage room for drugs, injections room, minor theatre and mini laboratory. The 3 rooms are approximately 20 m^2 each, totalling 60 m^2. Other important gadgets in relation to PV energy calculation in this building include a small vaccines refrigerator (Dometic RCW 42EG) and a microscope currently using a standard 6V 18A 108 W microscope illuminator bulb (EDW 18/a 6/v). With proper laboratory design and sample preparations, it is still possible to use ordinary light microscopes for most diagnostic tasks. Alternatively, in case artificial lighting is necessary, light emitting diodes (LED) because of their higher energy efficiency are most appropriate for microscopy in PV powered dispensaries. It is just a question of time before the prices for LED lighting devices for microscopy are sufficiently low to be more widely applicable in such medical units in rural areas.
- The main wards building with two sides, the male and female wards with 10 beds each, (approximately 2x 5x10=100m^2)
- The maternity wing, with a specialised labour ward (20 m^2), neonatal ward (60m^2) and a midwives' office (12m^2).
- Other buildings related to patients' care at Kishanje dispensary include the patients' kitchen (used by visiting relatives), (12 m^2) and patients and visitors' toiletry house with separate facilities for men and women, each comprising of a pit latrine (2m^2) and washroom (2m^2).

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[42] http://www.dometic.com/templates/fp.aspx?id=496

- Staff housing facilities include the Clinical Assistant's residence house and nurses' residence house both with one living room and two bedrooms each, plus one separate kitchen (approx. 9m²) and a detached toilet house to each residence comprising of and pit latrine (2m²) and a bathroom (2m²). The rooms in the main house have these typical dimensions: 16 m² for sitting rooms, 12m² for bedrooms

Electric energy demand at this dispensary is for lighting, powering of small medical gadgets such as refrigerators, microscopes and cellphone charging as well as demand in staff residential quarters has been calculated using excel (sheet attached) and found to be as follows:

Energy for lighting in patient care unit ……………………….. = 5.672kWh/d
Energy for lighting in staff residential quarters……………….. = 1.016 kWh/d
Energy for refrigeration and other running electric gadgets….. = 2.720kWh/d.
Total electric energy demand at Kishanje dispensary…………. **= 9.408kWh/d**

4.2.6. PV requirement to satisfy the single dispensary energy demand

The efficiency of PV cells ranges between 9%- 16% for amorphous and Monocrystalline silicon cells but for complete modules the overall efficiency is lower. The best commercially available polycrystalline modules however have an average efficiency of 13%. As argued before, based on Hankins (1995), for stand-alone PV we assume solar harvests of 4.5 kWh/m²/d, and module efficiency of 13%. So, to satisfy a need of 9.4 kWh/d one would need 9.408/4.5/0.13 = 16.08 m² of PV polycristalline silicon PV modules on that single rural dispensary. Conversely, given low mechanisation in tropical building and installations we take the currently decide to use 50 W_p polycristalline silicon modules and given 4.5 peak hours per day, we may satisfy the demand by having 9408 /4.5/50 =41.8=> **42 modules** @ 50Wp for a dispensary such as one at Kishanje.

Energy storage

For electric energy storage, we may assume a 12V or 24V distributed storage system based on wet lead-acid standard automotive batteries with batteries with 50% depth of discharge (DOD) or specialized solar batteries with 80% DOD as in the case of schools. However, in the case of dispensaries, work is assumed to be full-time without week-ends or public holidays. So we do not have a day without work in which batteries may be charged without discharge. For this reason, we may prudently accept a 2 days power supply security margin on our battery storage system. We may therefore calculate the required storage capacity as seen in table.

Table 4.5: Battery storage capacities (in Ah) for powering a dispensary such as one at Kishanje according to battery type and DC system voltages.

Battery type / System Voltage	Standard Automotive battery (DOD = 50%)	Deep cycle "Solar"battery (DOD = 80%)
12V DC	3136	1960
24V DC	1568	980

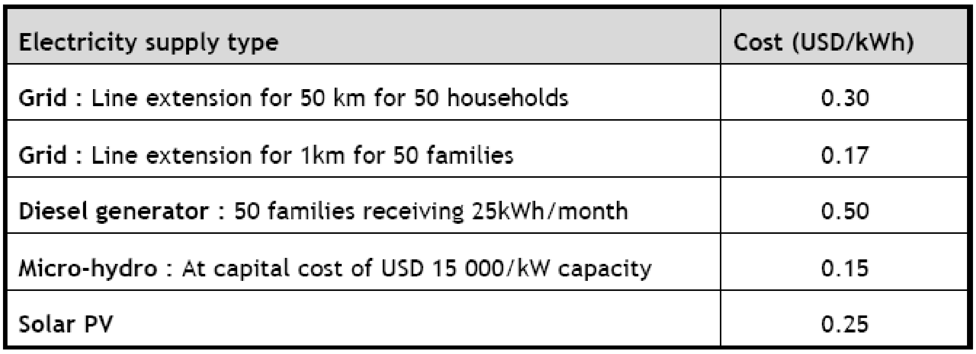
At 12V DC system voltage, such a dispensary requires **784 Ah** but this capacity is modified by the battery type used and the energy security degree required. In case of use of automobile batteries @ 50%DOD and 2 days' energy security, the installed battery capacity must be **3136 Ah** (=32 batteries@100Ah). In the case of specialised deep cycle solar batteries at the same system voltage and energy security provision, the battery capacity installed would be **1960 Ah** (= 20 batteries @100 Ah). As stated in the case of primary schools before, at 24V system voltage, the mathematical capacity would be halved, but the number of batteries will be the same, only connected in parallel strings of pairs of series connected batteries for 12V pack batteries or parallel connections of strings of 12 series connected cells for deep cycle individual cells @ 2V.

4.2.7. Electric power and energy demand for all dispensaries in Tanzania.

According to *Juntunen (2001)* in year 2000 Tanzania had 2644 dispensaries. Assuming all these dispensaries to have the same requirements as Kishanje, these dispensaries in Tanzania would have an energy demand of **24,874.752 kWh/day** (= approx. 24.9 GWh/day) boiling down to an annual energy demand of 9079284,48 kWh/annum (=9079,2 GWh/a) which can me provided by **111048 PV modules @ $50W_p$** and **52880 deep cycle solar batteries@100 Ah** over 12V systems.

In order to really appreciate the value of PV for a given activity at a given location, the cost of PV should always be evaluated in comparison with other locally available options of of electrification. A recent World Bank study gives the following comparison indicators:

Table 4.6: Comparison of typical costs for electricity supply types in Africa



Electricity supply type	Cost (USD/kWh)
Grid : Line extension for 50 km for 50 households	0.30
Grid : Line extension for 1km for 50 families	0.17
Diesel generator : 50 families receiving 25kWh/month	0.50
Micro-hydro : At capital cost of USD 15 000/kW capacity	0.15
Solar PV	0.25

Improving Energy supplies for two billion people, World Bank, Washington, 1996 (Forslund et al. (2007)

4.2.8. Energy demand in other medical facilities & services

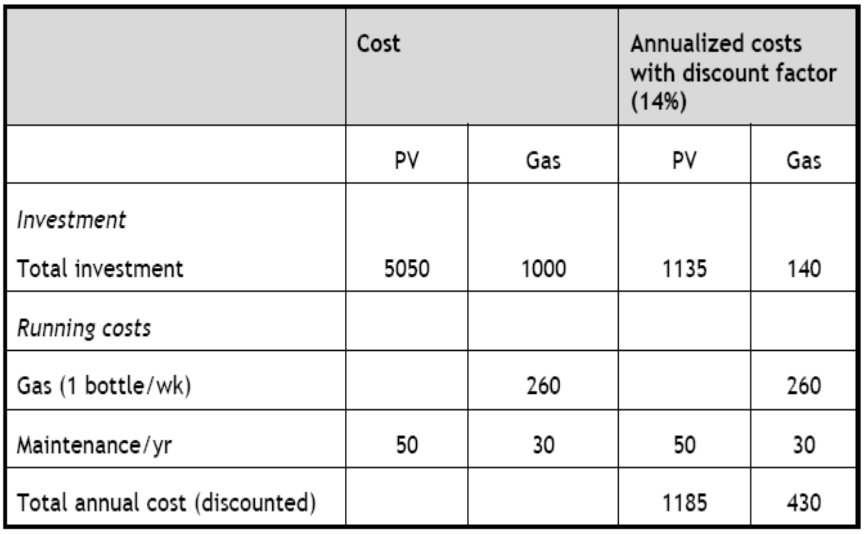
From the 1995 statistics, by then Tanzania had a population of 27,941, 103 persons sharing 31,636 beds in all health facilities in the country, making the population per bed ratio of 883 persons per health facility bed. Definitely the population has since then increased. The latest available statistics indicate a population of approximately 36,308,000 for 2004. Assuming a commensurate increase in hospital facilities provision, it is possible for Tanzania by that date to have 36,308,000/ 883 = 41,119 beds in all health facilities. Using these figures and the approximate space requirement of about 5m^2/bed we come to the approximate hospital ward space requirement of 5* 41,119 = 205,595 m^2

District hospitals and other medical institutions above district level are usually located in urban areas and therefore connected to electric mains. In this case PV though useful may not be quite obligatory. But for dispensaries and health centers, most of which are located in rural areas, PV may be the only reasonable means to provide affordable electricity to power various equipment and services such as:

- **Night lighting:** From the 1995 statistics projected to 2004 as quoted above, for example, 205, 592 m2 of hospital ward space were required in the whole of Tanzania. This space, when lighted for about 5 hours per night at 5 W/m2, would consume 5,139,875 Wh/d (i.e. 5,140 kWh/d) only in the whole of Tanzania. Taking the worst sunshine conditions of 4.5 h_p/d (peak hours per day), this means a requirement of 1142194.4W_p (**1,142.2 kW_p**) of PV modules to satisfy the lighting needs in all patients wards in all health provision facilities in Tanzania. On the other hand if we considered average sunshine conditions of about 5.5 hp/d then the PV module requirement for the same lighting load would fall down to 934522.7 Wp (934.5 kWp)
- **Medical refrigeration:** Each small refrigeration unit used for medical purposes (such as vaccine storage, blood banks etc) consumes approx. **1.9 kWh/day**. It should be noted here, however, that in the field of medical refrigeration, in some cases gas and kerosene

powered refrigerators offer strong competition to PV. *Forslund & Syngellakis (2000)* quoting a 1991 WHO large scale survey in their ENABLE project paper comparing PV and Gas refrigeration have found out that gas powered medical refrigeration was cheaper compared to the PV powered alternative. (*http://www.enable.nu/publication/D_1_1_RETs_overview.pdf*) The comparison is as showen on table 4.4

Table 4.7: Vaccine refrigerator: lessons learned from large-scale programme survey, Geneva (WHO, 1991)



	Cost		Annualized costs with discount factor (14%)	
	PV	Gas	PV	Gas
Investment Total investment	5050	1000	1135	140
Running costs				
Gas (1 bottle/wk)		260		260
Maintenance/yr	50	30	50	30
Total annual cost (discounted)			1185	430

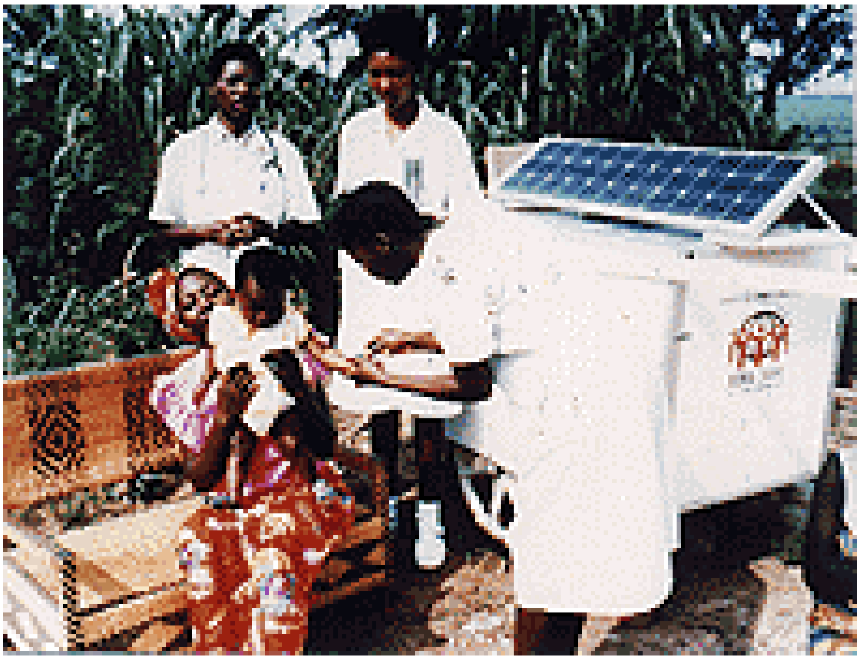


Fig. 4.6: PV in child vaccination in Kenya [43]

- **Diagnostic tools**: many diagnostic tools, laboratory equipment and other clinical electric and electronic equipment and installations, e.g. centrifuges, microscopes etc are usually low power appliances that can be easily and economically powered by PV directly or through PV charged batteries. More information about technical details (including power consumption) of medical equipment can be obtained from specialised selection aid sites such as MEDCOMPARE http://www.medcompare.com/spotlight.asp?spotlightid=117 or from manufacturers, dealers, international suppliers. Diagnostic centrifuges for example

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[43] ESRI http://esri.energyprojects.net/

range from 100W-200W (e.g The Model 614B, 6-Place Fixed-Angle Centrifuge from **Drucker Co)**

- **ICT in medical care (telemedicine or e-Health)**: telecommunication facilities computers and other information storage and communication systems for use in medical care are very good candidates for PV applications because of their relatively low power demand. Incorporated or installable energy storage mechanisms can be of great help in view of the users' lack of control over sunshine conditions. In spheres of medical care from medical supplies logistics and administration to operative patient care PV and ICT can work together like twins. PV can power the Information and Communication Technology (ICT) in the health sector internet to facilitate data communication within a single office or hospital and between different offices and hospitals over the internet or other communication networks. Such programs, collectively called e-health programs, already exist in other countries such as Australia. In the Australian e-health system, for example, different financing programs and grants are given to facilitate broadband internet connectivity for healthcare purposes [[44]]. In recent times, the European Space Agency (ESA), realising the importance of ICT in medical care in Africa has set-up the Telemedicine Task Force (TTF) for sub-Saharan Africa and have developed the HEWS for epidemiological monitoring and control, which applies satellite communication The system has already been tested in Angola among others and found to be suitable especially in remote areas where the standard telecommunication systems are either malfunctional or totally absent *(Parentela 2008)* "ESA supports efforts to protect public health and safety" [[45]]. An ESA newsrelease on 17 November 2008 (Accessed same day, 17 November 2008). A complete SWOT analysis of ICT application medical care in Africa was reported by *Asamoah-Odei et. al., (2007)***,** however, without reliable power supply, ICT would not work well.

PV in public health enhancement: A lot can be done using PV in the public health domain. Health campaigns in ordinary electronic media, for example, would be could be enhanced by PV power supply at remote reception areas. Some external donors e.g. the Clinton Global Initiative CGI"**[[46]]** have already noticed this potential and are actively engaged. PV electricity is very important for running electronic devices, which are nowadays used more and more in medical care, right from preventive services, through diagnosis and treatment of disease and finally in convalescence and care of people suffering from effects /results of disease, disablement and old age. In addition electronic devices such as computers for example, are useful as a virtual reality simulation tools used in the training of medical personnel both at campuses and remotely. Training of health personnel has a great impact on public health as well. Finally, the role of PV in clean water supply and the importance of clean water supply in good public health maintenance cannot be overemphasized.

4.3. SPECIAL CASE No.3 PUBLIC ADMINISTRATION

4.3.1. The Tanzanian public administration system

The United Republic of Tanzania is a composite state made up from a union of two former sovereign states, namely the Republic of Tanganyika, comprising mainly of the mainland part, and the Peoples Republic of Zanzibar comprising mainly of two big islands, Pemba and Unguja off the East African coast, adjacent to Tanganyika. The type of unity government for the United Republic of Tanzania is a bit unique. Quite unlike the well known federal systems of government with separate government for each federal state plus a single union/federal government, the Tan-

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[44] http://www.health.gov.au/internet/wcms/publishing.nsf/Content/health-ehealth-broadband-grants.html

[45] http://www.esa.int/esaTE/SEMGBL4DHNF_index_0.html

[46] Clinton Global Initiative (2006):"Global Health" Working Session III http://clintonglobalinitiative.net/NETCOMMUNITY/Page.aspx?&pid=444&srcid=444

zanian union government is organised under a two government set-up under which, there is a "Union Government" which caters for both union and mainland matters together as well as an autonomous "Zanzibar Government" which caters for matters pertaining to Zanzibar alone. Regional administration and local Government happens to be a non-union matter and so there are separate administration systems, namely for Zanzibar under the Zanzibar autonomous government and for the mainland, under the union government. So unless otherwise expressly stated, further discussions about administration under the union government will actually pertain to the mainland alone.

Tanzania is administratively divided into 26 Regions (21 on the mainland and 5 on Zanzibar). The regions are further subdivided into 114 Districts which are administered through 133 District Councils under District Executive Directors (DEDs). The districts are mainly rural, but some urban centers, mainly regional administrative headquarters, have district status with a separate administration where the "Town/Municipal Council" under the "Town/Municipal Director" serves as the equivalent of the rural "District Council" under the DED. The rural districts far from regional headquarters are administered from small towns within their jurisdictional area, excapt for the district surrounding regional headquarters which is itself administered from its regional headquarter town, albeit housed in a separate office building designated for that purpose. The city of Dar es Salaam has the status of a region, with its own three districts of Kinondoni, Ilala and Temeke, which are administratively considered as Municipalities within Dar es Salaam city. The distinction between a "Town", "Municipal" and "City" status is based on population size and other economic factors in increasing order respectively. The Districts are further subdivided into "Divisions" *(Tarafa)*, of which there are 516 in the whole of mainland Tanzania. The "*Tarafas"*, are further subdivided into "Wards" (called *Kata* on the mainland part, and *Shehiya* in Zanzibar). Villages *(Vijiji)* in rural areas and "Streets" (*Mitaa*) in urban areas are the smallest governmental administrative units amalgamating into the above named "Wards". The "*Mtaa"* (singular of "*Mitaa"* in Kiswahili) is the urban equivalent of the rural Village *(Kijiji)*.

According to interviews with officials of the Prime Minister' Office, responsible for Regional Administration and Local government (PMO-RALG) (20 Jul 2007), there are 10,344 villages, 1755 urban *Mitaa* organised under 2555 Wards *(Kata)* in Mainland Tanzania. Most of these grassroots and low-level administrative instances are not "powered" in the sense that they do not have access to grid electricity, and to those that are connected to electric mains supply, the electricity itself is not as readily available as would normally be expected. Sometimes you have "blackouts" or "brownouts" for hours, days, weeks or even months at a stretch. Lack of access to electricity especially below district level, is a big handicap in all government administrative work not only in Tanzania, but in many other tropical developing countries as well.

4.3.2. Energy demand and supply in public administration

From the fact that most government offices work only during daytime, (officially 08:00-14:00 hrs non-stop), and considering the fact that the land is tropical, if public offices are well designed, then they should not have an energy demand for "lighting". However, there is a marked need for air conditioning, cooling in coastal areas and even cooling in some highland areas. These thermal energy needs can best be addressed using other methods beyond the scope of this thesis. However, to mention just a few groups one may consider constructive methods (e.g. materials and components, orientation, fenestration, insulation etc) and/or direct thermal energy application methods (e.g. solar-thermal, geo-thermal and sustainable fuels, all of which have technologies for both cooling and heating). Ventilation, both natural and forced, as well as taking advantage of diurnal (day/night) changes would also be important to consider in building comfort management, especially in combination with the above mentioned methods.

Considering PV, although it may be used for ventilation especially in combination with other thermal control methods, its main general application in public administration, however, would be supplying powering in those areas and activities where electricity would be the only or best form of energy input. Traditionally, the "usual" application of electricity in government administrative buildings at many levels is considered to be for lighting and in some extremely lucky circumstances, powering of refrigeration and air conditioning systems. However it is the contention of the current researcher that the most meaningful application of electricity at all levels of public administration would be to power ICT. This would enable the long overdue **"information revolution" in the whole government administrative system**, from the lowest instances of villages *(vijiji)* and "streets" *(mitaa)* to the very top, i.e. the Prime ministers' office, responsible for regional administration and local government (PMO-RALG). Any administration is heavily reliant on horizontal and vertical flow of information through communication (i.e. same level and up-&-down in hierarchy, respectively), within the system. The administration process in many states in the world is slow and cumbersome because of the slow flow of information and inefficient information storage and retrieval systems. This problem is aggravated in many Third World countries, including Tanzania, partly because of lack of use of modern information management tools and methods, which in turn are heavily reliant on availability and security of electricity. The electric energy demand for public administration for rural areas of Tanzania is estimated as follows:

According to data personally obtained by this researcher from the Prime Minister's Office responsible for rural administration and local government (PMO-RALG), by August 2007 in Mainland Tanzania, there were 10,344 registered rural settlements i.e. villages *(vijiji)*, 1,755 urban settlements *(mitaa)*, 2555 "wards" *(kata)* and 516 "divisions" *(tarafa)*, below 133 district councils under District Executive Directors (DED's). The *de-facto* government policy actively implemented since independence was to strive for provision of mains grid electricity to "at least" district headquarters. Although this policy is not fully implemented to-date, at least there are visible efforts being made towards this goal. In district headquarter towns where mains electricity cannot be provided from the centralised national grid system, it is being provided in using localised diesel generators running on petroleum diesel. Below district level, however, availability of electricity is considered only as good-luck. Although it is known that some district headquarters (especially the newly established ones) do not have electricity, and that some local government offices below district level (especially in urban areas including some *kata* and *mitaa* offices in fact do have (or can be easily provided with) electricity, for lack of accurate data and only for the purpose of this thesis we have to make the following **assumptions**:

- all district headquarters have mains electricity
- all government offices below district level in both rural and urban areas also do not have mains electricity
- all public offices at and above district level will power their activities (including ICT) using mains grid electricity. (much as we know it is erratic and sometimes unstable).
- it is only those public administration buildings below district level that actually need PV for powering ICT in their work as a matter of absolute necessity. They also need PV for their residences assumed to be similar to those for health personnel.
- the necessary ICT equipment include at least one internet connected computer (laptop) with a multipurpose peripheral serving as printer-scanner-copier-fax in one appliance. Although the peripheral is normally not constantly in use, its power demand (given for Brother MFC 420 CN All-in-One Printer, Copier, Scanner & Fax by the manufacturer as 4/6/29W in Sleep/Standby/Peak modes, http://philadelphia.craigslist.org/ele/970639146.html) is assumed to be around 20 W working constantly together with its computer. The combined power demand of this complex is estimated at 120W
- the duration of ICT use is differentiated along the hierarchical gradient with the lowest use at 4 hours/day in villages and urban settlements*(vijiji & mitaa)*, 5 hours/day at the

ward *(kata)* level and 6 hours/day at division (tarafa) level. The rest of the time the administrators are doing other activities such as making site visits and attending to local community needs in their jurisdictional areas. This time schedule is only average because the higher the administrative rank, the bigger the jurisdictional area, therefore, the more the reliance on transmitted information and the longer it would take in case of a site visit.

- The working week is 5 days but when public holidays are also taken into account, we get 250 working days a year.
- all governments offices below district level are manned by at least a single individual therefore need at lest one residential house for their officers

Electricity demand for public administration at the lowest level (the smallest unit).

From the above mentioned assumptions can be calculated that the public administration system at its lowest level, the village *(kijiji)* or urban settlement *(mtaa)* needs to run a single computer and its peripherals, for only four hours a day, making 120 W*4h = 480Wh/day per village or urban settlement. This electricity need for village administrative ICT would can be covered by 480/4.5 = 106.7 W_p (or 2 PV modules@55W_p) and 480/12=40Wh of battery storage (=2 automotive batteries @ 40Ah or 1 small deep cycle battery @ 50 Ah).

Assuming that the administrative personnel working in the above named posts reside in buildings similar to those of health workers and have similar electricity requirements, namely 728 Wh/day per household (naturally they don't cook with electricity) Then the maximum total electricity demand per administrative official at the village level would be 480+728 = 1208Wh/day, which would be covered by 1208/4.5 = 268.4 W_p (=3 standard PV modules @ 100W_p) and 1208/12 = 100.7 Ah (=2 automotive batteries @100Ah or 1 standard deep cycle battery @135Ah). It should be noted that staff residences are occupied everyday including week-ends and public holidays (365 days a year) while administrative officer are off-duty on week-ends and public holidays making only approximately 250 annual working days. So there is a reasonable energy security margin because if other assumptions remain constant then the actual energy consumption is somewhat less than the calculated resources which is, in addition, based on the solar harvest average for the worst month in a year.

Electricity demand for public administration at national level

Given the number of administrative units as stated earlier and the assumptions made above if we take care of ICT and residential needs for only the 10,344 villages (*vijiji*), 1,755 urban settlements *(mitaa)* and 2555 "wards" (*kata*) and 516 "divisions" *(tarafa)* according to the assumptions indicated above we get the results as indicated in table 4.5 and table 4.6 below

Table 4.8: Energy demand for ICT in Tanzania's public administration below district level

	Number	Unit power	use dura-tion	energy demand	PV power required	Battery capacity
	[Units]	[W]	[h/day]	[Wh/day]	[Wp]	[Ah]
Vijiji	10344	120	4	4965120	1103360	413760
Mitaa	1755	120	4	842400	187200	70200
Kata	2555	120	5	1533000	340666,667	127750
Tarafa	516	120	6	371520	82560	30960
TOTAL				7712040	1713786,67	642670

Table 4.9: Energy demand for residences of Administrative personnel below district level

	Number	Unit Energy demand	use dura-tion	Total energy demand	PV power required	Battery capacity
	[Units]	[Wh/day]	[h/day]	[Wh/day]	[Wp]	[Ah]
Vijiji	10344	728	N/A	7530432	1673429,3	627536
Mitaa	1755	728	N/A	1277640	283920,0	106470
Kata	2555	728	N/A	1860040	413342,2	155003
Tarafa	516	728	N/A	375648	83477,3	31304
TOTAL				11043760	2454168,9	920313

The question of provision of fast communication systems from simple cellphones to computer networks, made available to these same officers is still not yet being debated. Although one may cite the lack of awareness on the part of some top official senior government decision makers about current ICT possibilities in public administration, the question of provision of reliable power supply to run these informatics tools is still a serious issue to contend with before any idea of provision of such electronic gadgets can even be thought about.

At present, mains electricity is available at District level, (albeit intermittent and unreliable). In most instances below district level, mains electricity is not available at all, especially in rural areas. This means all modern ICT based communication gadgets from simple cellphone communication to the Internet and its derivatives such as e-mail, through realtime on-line communication commonly referred to as “chatting”, to actual videoconferencing cannot be used, because they are all powered by electricity, either directly or through rechargeable batteries. Traditionally electric mains are absent and rechargeable batteries are cumbersome to use without recharging mains. Non rechargeable batteries are expensive. However, technology is moving faster than tide. It is now possible to surf the Internet over modern third generation (3G) and fourth generation (4G) cellophanes, which are already beginning appear on the World Market including some remote rural areas in Africa. Although these gadgets are still to make their way into government business as usual they are already entering private business circles and “circles of Prestige” at least in some quarters in Africa. If the governments of Third World Tropical countries including Tanzania are to benefit from this Information Technology Revolution and be able to harness the power of these gadgets, they have no way except to come up with a reasonably affordable power supply system for powering this small electronic communication devices. This is where PV technology comes in handy.

In this situation PV comes in as a unique solution to the low power electricity supply needs typical of ICT demands. PV provides the necessary electricity to power the above-mentioned administrative-communication gadgets and facilities of any size. For example, the pictures hereunder show PV gadgets suitable for charging small cellphones. In some commercial arrangements these PV modules may be **marketed together with the cellphones** just in the same way as wall-plug charging adapters are currently bundled together with modern cellphones they are needed to power.

Fig. 4.7: PV powered cellphone charging systems from Photon Technology Inc. [47]

Larger ICT systems may require roof mounted or completely Roof Integrated PV systems and appropriately matched storage systems, to be provided together with those ICT systems they are meant to power. The secret of the game lies in **the marketing not of PV as a separate power supply system but rather in the marketing of complete service systems with matched PV as their power supply** option. In most instances, government administrative work is usually carried out during daytime hours, just as stated in the case of primary schools, in properly designed tropical buildings, the question of office illumination using artificial light sources during daytime working hours should not arise. There are many day lighting options for both residential and indoor working spaces, that can be used. However, in very special circumstances, or in cases where office space is intended for night use purposes, PV lighting systems may be included if necessary.

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[47] http://www.photontek.com/

Summary of Chapter 5: Based on the calculations made in chapter 6 above, a clear picture of the solution is presented in form of the concept of integration of Photovoltaics elements into buildings thereby replacing conventional building elements with those that generate electricity in addition to their more traditional role.

5. INTERGRATING PV MODULES IN TROPICAL BUILDINGS

5.1. The Concept of Building Integrated Photovoltaics (BIPV)

Photovoltaic modules are said to be integrated into a building, when they are mounted directly onto, or form part of a building element, e.g. a façade, wall, roof etc. There are three ways of achieving BIPV.

- The PV modules being mounted on top of a building element
- The PV modules being integrated into a building component.
- The PV modules replacing the whole or part of a building element.

In all cases, in addition to generating electricity BIPV seeks to offer some elements of "additional value" to the building. In the former case, the additional value can be aesthetic and prestige. In the middle case the PV can improve the traditional functional performance of the component in which it is integrated, in addition to good aesthetics and prestige. For example a thin film PV layer on a roof shingle or tile can render the shingle or tile more weather resistant and/or watertight. In the latter case, in addition to enhancement of aesthetics and prestige, the PV modules must take over the function of the building element they replace. For example, a PV integrated window must perform all the functions of the traditional window such as selective admission of daylight into the building, offering external view, facilitating natural ventilation etc, while at the same time continuing the wall function of forming (or demarcating) a barrier between the inside and the outside. A PV integrated roof in addition to generating electricity and providing good aesthetics and prestige, must also perform the traditional functions of a roof such as protection of the inside from direct sun and rain. In all cases it is important that the part of the building onto which PV is located be designed to benefit from maximum exposure to solar radiation. This in turn influences the orientation of the building or the element in question, the absolute and relative sizing of the PV-holding element and element, etc.

5.2. Specificity of tropical BIPV

5.2.1. Tropical solar geometry

As distinct from its behaviour in the temperate zone, where sun skirts around the vertical axis, tropical sun goes from East to West directly through the Zenith or with very small seasonal declinations to both the North and South. The diagrams following below, graphically illustrate the difference in Solar geometries between tropical and temperate regions, and to support the authors argument for a special design tropical BIPV. As can be seen from fig. 1.6, in tropical areas there are slight seasonal variations in solar declination to both the North and South each year whereas the solar declination in temperate areas, e.g. Dortmund, Germany, is always in one orientation, only seasonally differing in maximum daily sun elevation angle. This main distinction of tropical solar geometry from that in the temperate zones of the Northern or Southern hemispheres, has a strong bearing on tropical BIPV which, as a result, must differ from temperate BIPV.

5.2.2. Criteria for Assessing the Solar Energy potential of a Locality

There are several ways of assessing the solar energy potential of a given place or object: i.e. the daily, monthly and annual solar gains, both as averages and in absolute totals. Each assessment criterion has its own use. For the purposes of assessing the potential of permanently fixed modules and, therefore, determining their best (optimal) tilt angle it is important to look at annual solar gains, whereas for the purpose of solar array sizing, for a given expected load (building, pumping station, telecommunications center) the daily gains in the worst month offer the most secure design criterion if PV is the only electric energy source under consideration. The monthly solar gains help in determining the “best” and “worst” months or seasons for onward sizing calculations indicated above. As a result of the Solar geometry described above, the daily solar irradiation on inclined surfaces at different latitudes is as appears hereunder:

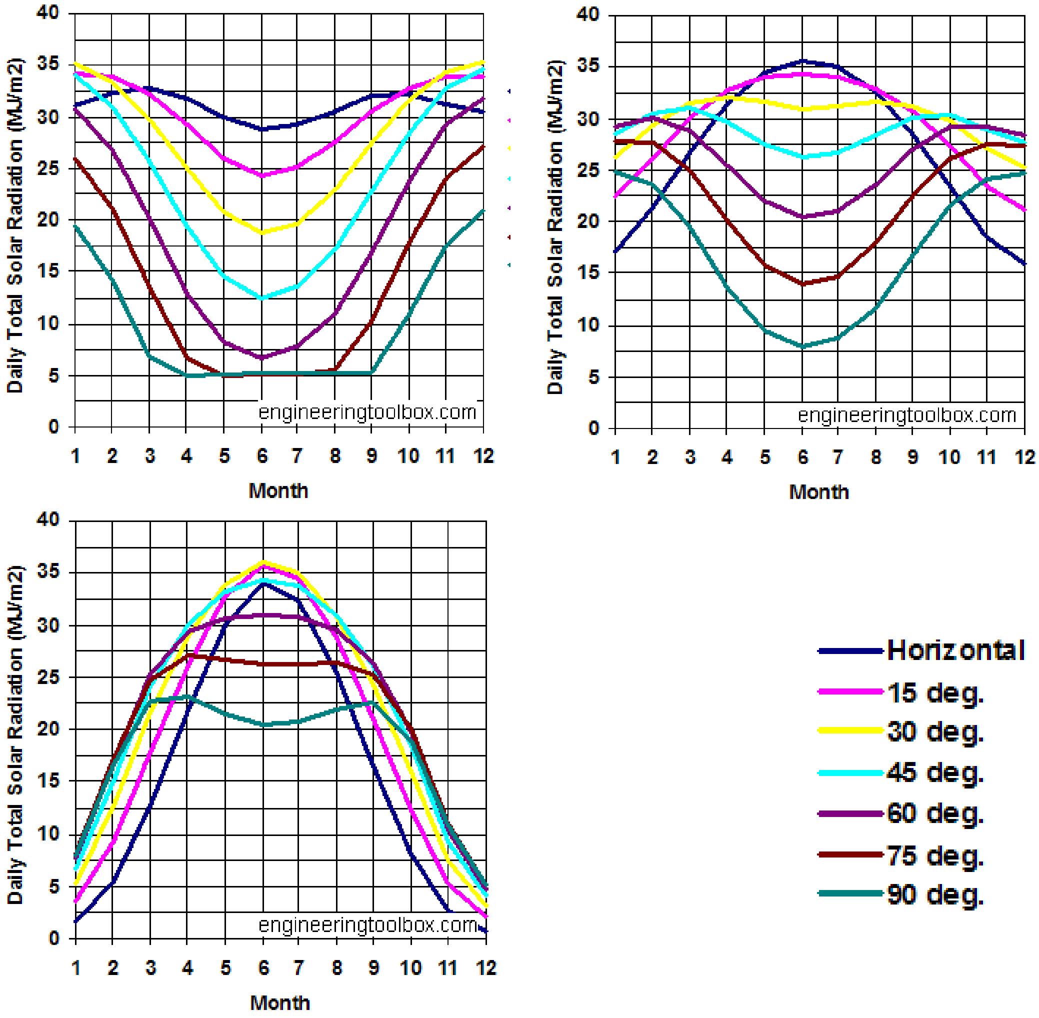

Fig. 5.1: Solar Radiation diagrams for Topical (Equatorial) Latitude 0^{o} (a), Warm Temperate Latitude 30°N (b) and Cool temperate Latitude 60° N [48]
(for ease of conversion 1 MJ = 0.278 kWh = 239 kcal = 948 Btu, 1 m^2 = 1550 in^2 = 10.764 ft^2)

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[48] http://www.engineeringtoolbox.com/

5.3. Simulations of annual solar gains using PVSYST, TRNSYS & METEONORM

In order to determine the best module inclination angles for tropical BIPV at a given location and to further demonstrate the effect of Solar Geometry on solar energy gains in tropical areas, simulations carried out for Dar es Salaam, Tanzania (6 deg. S) using PVSYST 4.21 and TRNSYS 16 simulation software, based on data from METEONORM 5.0. In these simulations, annual solar irradiation incident on an inclined surface in different inclinations and orientation was calculated and presented both in absolute terms and as a fraction of the best possible annual solar gain at that locality. The general results obtained indicated that the **maximum solar radiation gain 1771 kWh/m²/annum** and the **best orientation** of the surface capturing it (an array of PV module in our case) is **horizontal**. It was furthermore shown that a slight inclination of this surface (around 10°) in any direction or orientation will still give very good result in the optimal range of 100%. However, at slightly greater tilt the Northern direction takes precedence. Such an inclination will still give optimal solar gain results up to almost 18°, whereas for the same results in other orientations, the inclination must be reduced down to about 12° in the Southern orientation. At greater inclinations we see a general reduction in overall solar gains compared to the horizontal and observe an interesting fact that the Eastern and Western orientations start taking precedence over the Northern inclination. This is because of the possibility of perpendicular incident solar radiation in the early to mid morning and mid- to late afternoon respectively.

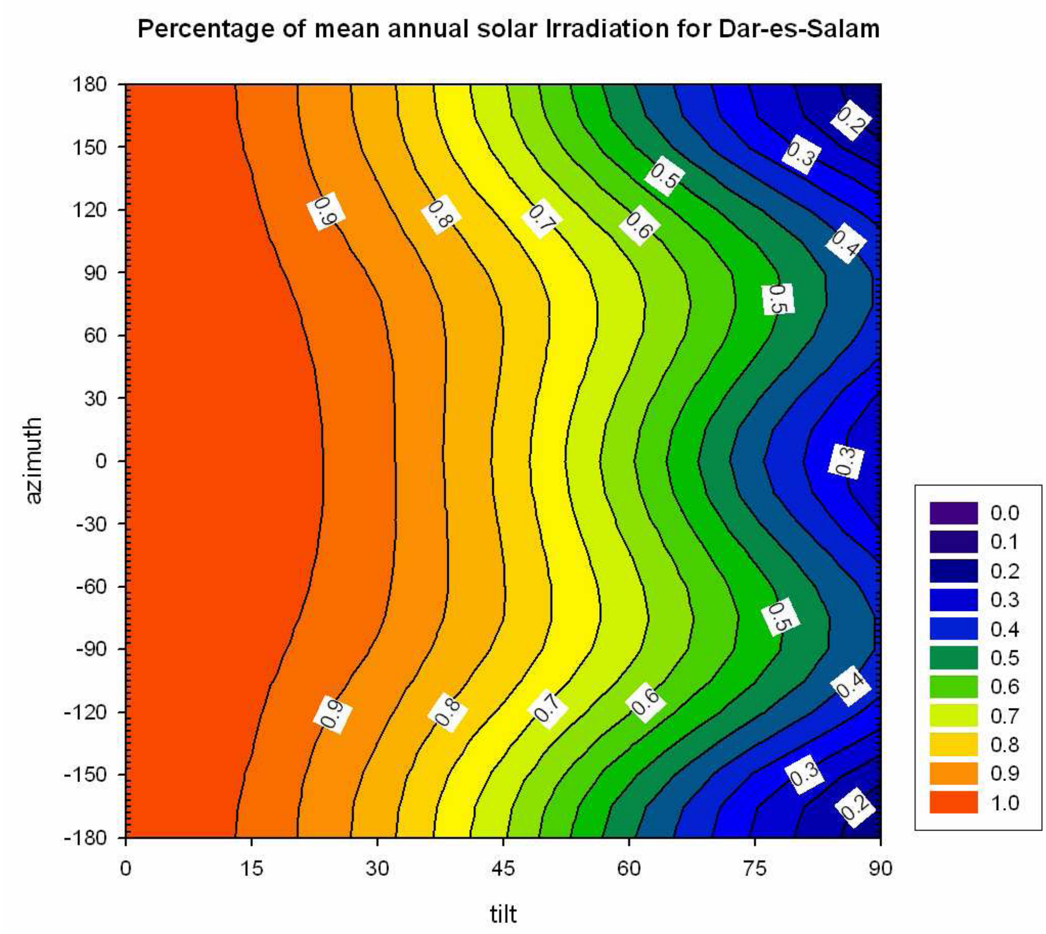

Fig. 5.2: Annual Solar gains as a function of PV module inclination and orientation (in a fraction relative to the best possible annual solar gains)

For example, in comparison to the optimal (horizontal) position, a fixed module tilt of 45° will yield a 65% overall solar gain in the Southern orientation, and about 80% in the Western and Eastern orientations but about 78% in the Northern orientation, whereas 60° deg module tilt will yield about 45% in the Southern orientation, about 65% in the Eastern or Western orientation but only 60% in the Northern orientation. At a 75° tilt, the Southern orientation receiving only about 30% has the lowest solar gains while the Eastern and Western orientations gaining about 50% have the best results and the Northern orientation at about 43 40% is somewhat intermediate. Understandably, therefore vertically hanging PV modules in tropical regions will have the worst overall gains. However, it is seen that the Eastern and Western oriented vertical surfaces receive relatively higher overall solar gains (almost 40% compared to the horizontal) while solar gains to the Northern oriented vertical surfaces fall to about 25% and the Southern oriented vertical surfaces receive less than 20% relative to the optimal (horizontal) position. These results have many more significant implications in tropical solar building design beyond only PV applications. They can also help optimising orientations of streets, buildings, building facades, sizing of windows and other fenestration parameters and optimisation of building heights and street widths in architecture and urban design.

On the other hand this fact highlights the importance of the paying special attention to the Western and Eastern oriented vertical walls and building facades during the design of tropical buildings. It is from here that comes the rule of thumb of avoiding Western fenestration or location of bedrooms in the Hot-&-Humid coastal tropical climate such as Dar es Salaam, while such an orientation of fenestration and bedroom locations would be desirable in the cooler tropical highland areas such as Arusha, Bukoba and Iringa, in Tanzania, as well as Nairobi, Kigali or Mbarara in the rest of East Africa. (Ironically, these places are very close to the equator, a situation that belies their temperature behaviour. An inexperienced foreigner may imagine them to be very hot due to their equatorial position).

5.4. PV module materials for BIPV

There are no special PV module materials typical for tropical BIPV. In principle ordinary PV materials as described in Chapter 2 above can be used, provided basic challenges are dealt with. From the need for using the roof getting the maximum Given the desirability of a horizontal For completely Roof Integrated tropical BIPV, these challenges are mainly associated with keeping the roof water-tight the structure of the PV modules which in turn is related to the type of cells and the substrate holding them. Rigid substrate Crystalline Silicon e.g. glass-glass or glass-plastic modules, Thin film on rigid substrate modules e.g. Amorphous Silicon on glass or CIS/CIGS on metal (such as UNI Solar Triple Junction standing seam) as well as Flexible substrate thin film PV modules e.g. Amorphous Silicon on plastic substrate or CIS/CIGS on plastic substrate (UNI Solar Triple Junction).

Fig. 5.3: "Triple Junction" thin film PV module on a flexible substrate, Suitable for installation on curved roof surfaces in tropical BIPV [49]

5.5. Fixed or tracking modules for BIPV?

For maximum solar radiation gain a PV module setting perpendicular to the incident solar radiation is necessary. In both temperate and tropical cases, since the sun is in constant motion on both daily and seasonal rhythms, a two axis solar tracking system will be of best advantage. In

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[49] Hug (2007) www.solarserver.de/solarmagazin/solar-report_0607_e.html

order to secure the best positions for maximum solar gain, either the whole buildings or its parts mounted with PV have to move in consonance with the sun for best solar position. Such buildings have been built and are still are in existence.

A few examples of buildings with solar tracking PV devices have been built and some still exist. However, most of these buildings were realised in temperate regions and can, therefore, not quite directly be copied for tropical BIPV but can be made suitable for tropical applications after a few critical modifications (Tropicalization). A few examples of such buildings are depicted in Fig. 5.5 and Fig. 5.6 hereunder, together with commentary about the necessary modifications for their tropical versions. The Heliotrope in Freiburg, Germany (Fig. 5.4) is a good example of a solar tracking BIPV through movement of both the whole building and the PV array mounted in top of it. This is basically a rotating house with a PV array mounted on it in form of a big sail-like device on a central vertical axis. The building rotates about a vertical axis together with the PV array “sail” which then wings about a horizontal axis. The combined result is that the PV array performs a two axis solar tracking. The Extra advantage of rotation of the whole building is that the glass façade of the building can be rotated “into the sun” in order to have the much desired solar heating effect in winter, and “away from the sun” in order to prevent overheating in Summer. The “Expo-Tower Wesertal” (Technology Building) Am Ohrberg, in Germany is another example of BIPV with solar tracking in form of a fixed house with PV panels mounted on one façade (south facing) and on arm-like appendages at both ends of this south facing façade. These PV module bearing arms (or wings) are mounted on vertical axes and swing to face the sun as it moves around the house from the East in the morning, via south at midday to the West in the evening. This design is suitable for higher latitude areas in temperate zones. Were it to be built in the tropics a different wing design would have to be made. In a tropical version of such a building, the wings would have to swing vertically in the East–West orientation about roof edge mounted horizontal axes. In this design, in addition to electricity generation, the wings may provide solar shade on Eastern and Western oriented windows at the same time.

Fig. 5.4: The Heliotrope in Freiburg: Example of Solar Tracking BIPV (arch. Rolf Disch)

Fig. 5.5: Expo-Tower Wesertal Am Ohrberg: An example of BIPV with solar tracking [[50]]

Although in general, tracking systems in BIPV are technically feasible they, however, do pose special practical problems, the solutions of which demand extra investments in order to ensure their mechanical (structural) stability and optimal operation, both of which translate into extra financial investment in comparison with their non-tracking (fixed module position) cousins.

5.5.1. The Importance the Roof and Roof Design in tropical BIPV

As can be deduced from the PVSYST simulation described and analysed above, the most important building element for Tropical BIPV is the roof and/or its extensions. This is the main building envelope element that can provide the greatest horizontal or quasi-horizontal surfaces, which face the sun for the longest duration (on both daily and seasonal basis) without much risk of being shaded. So roof design for Tropical BIPV is a very important consideration because the roof is the building element most expected to carry the BIPV modules. The modules themselves may be superimposed on the existing roof or incorporated into the roof fabric itself, even replacing some (if not all) of the traditional roof top cover materials.

5.5.2. Module Inclination and Orientation in tropical BIPV

One of the ways of going around problems of extra financial investment and mechanical stability associated with solar tracking devices is to settle for a building with fixed orientation and inclination of PV mounted surfaces and building elements. The whole building orientation or the orientation and inclination of the PV bearing elements and surfaces are to be fixed so as to get maximum solar gain calculated on annual basis. The overall orientation guide has already been explained in connection with PVSYST simulation results diagram in section 5.1.1 above.

5.5.3. Rules of thumb for annual maximum solar gains

Whereas the rule of thumb in temperate BIPV is orientation of the PV elements towards the equator and inclination at around the angle equal to the latitude of the location, that one in tropical BIPV dictates a horizontal positioning of the modules which must be kept level in the East-West direction. Any big inclinations of PV module surfaces towards the east or west would give good solar gains only for part of the day and less than optimal for the other part. For example an inclination to the East will give good results in the morning while and lose the afternoon gains, while the opposite would be the case were the module surfaces to be inclined to the west. The deviation from the optimum gains will be greater with greater angles of inclination. So inclina-

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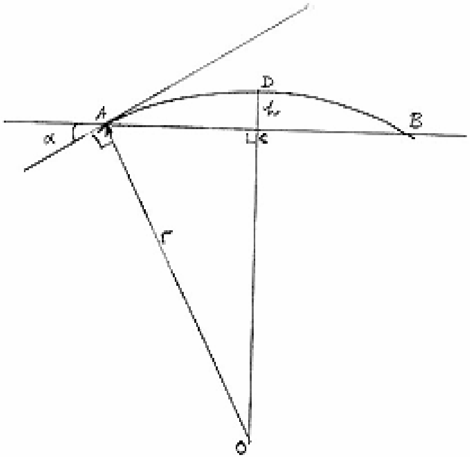
[50] http://www.architektur.tu-darmstadt.de/powerhouse/db/248,id_4,s_Projects.fb15

tions of the PV module surfaces in the east or west (rotation about a North-South axis) for permanent fixing in one position should be avoided in tropical BIPV. Inclination of the PV bearing surfaces towards the North or South that have a bearing on the maximum annual solar gains are dictated by the following three factors:

- The relative duration of seasonal variation solar position (solar declination)
- Timing and duration of seasonal variations in cloud cover (rainy and dry season)
- The need to facilitate cleaning of modules by water run-off (either by seasonal rains or by direct washing) in order to avoid dust deposition that may reduce the module efficiency.

5.5.4. Straight (Plane-Surface) or Curved Roofs in Tropical BIPV?

Roofs come in many shapes, the most common of which are described by *Schunck et al (1991)***.** From this collection, it is evident that all these roof styles can generally be divided into two main groups, namely, roofs with straight (plane) surfaces (polyhedral roof) and roofs with curved surfaces (cylindrical, spherical, hyperboloid or parts thereof). The choice between the two has traditionally been a question of pure aesthetical preferences of the Architects or their clients. However in tropical BIPV with the roof as the main element, the question of optimal (if not maximum) generation of electricity becomes equally (if not more) important as the architectonics. From the analysis of the simulation above we can deduce that both straight surface and curved surface roofs are possible. The only condition for both polyhedral and curved surface roofs is that for the best solar gains, the surfaces must be quasi-horizontal. While for polyhedral roofs it is easy to determine the inclination and orientation of the different planes of the roof surface, it is not that easy with curved surfaces. In this case we must deal not with the surfaces themselves, but with other parameters such as radii of curvature, tangents to these surfaces, spans and horizontal chords, as well as maximum heights or depths of crests above or below horizontal chords. In general for best annual solar gains with curved roof surfaces the angle between the tangent to the curve and the horizontal must not exceed the critical optimal inclination in the considered orientation, for that particular locality.



$$r = \frac{l}{2\sin\alpha}$$

$$h = \frac{l}{2}\frac{(1-\cos\alpha)}{\sin\alpha}$$

where

$r = \mathit{radius.of.curvature.of.roof}$

$l = AB = \mathit{roof.span.in.the.plane.of.curvature}$

$h = CD = \mathit{roof.curvature.crest.height.above.}\mathrm{tan}\mathit{gent.to.horiz.chord}$

$\alpha = \mathit{optimal.roof.curvature}\mathrm{tan}\mathit{gent.angle.to.the.horizontal}$

$\alpha \equiv \mathit{optimal.}\mathrm{modu}\mathit{le.tilt.angle(for.polyhedral.roofs)}$

$\mathit{for.best.Solar.gains.in.Dar.es.Salaam}$

$\alpha \le 15^0\ \mathit{in.Northern.orientation}$

$\alpha \le 10^0\mathit{.in.all.other.orientations}$

Fig. 5.6: The curve tangent rules for optimal BIPV on curved roofs

For tropical BIPV with small critical optimal angles, both concave and convex surfaces are equally possible to work with, but convex surfaces are easier to construct partly because of tradition and partly because of available building technologies and materials. Therefore, further discussion about curved roofs will deal mainly with convex structures. For purposes of ease of construction of convex external roof surfaces, the curved surfaces are best described in terms of radius of curvature and height of roof curvature crest above the horizontal span chord as explained by the formulae given hereunder:

Table 5.1: Challenges envisaged in tropical BIPV

No	Envisaged Challenge	Proposed Solution	Remarks
1.	Energy loss due to dust deposition on modules	regular washing, naturally by rain or artificially by pump& spray	(inclination for water run-off a necessary evil =>minimal necessary inclination)
2.	Energy loss due to module inclination and orientation	Small inclination angles Equatorial orientation is best (see remarks for comparison with horizontal position in the case of Da res salaam 6.3 deg.S.)	**Best Orientation N**. **Dar es Salaam example**: 100% gains obtainable at <15° N-orient or <5° E/W-orient 90% <25°. N-orient. < 20° E/W-orient.
3	Energy loss due to module overheating	Module ventilation Tandem installation with Thermal collectors(PVT). Thin film modules better than mono- and polycrystalline modules	Re: PVT:**Aste et al (2007**)
4.	Water tightness:	module overlapping, single module spans single module **zigzag** with non PV caps and valleys	Attention: Double inclination problem
5.	Double inclination	Very small angles esp. in E-W direction. (preferably < 10-15 deg.)	Main inclination (Equatorial) Minor inclination (E orW)
6.	Rigidity		Not always desired.
7	Fragility	Framed modules work better. Tempered glass modules Flexible thin film modules	
8	Fixing	Point (bolts, nails, screws) (glue?) Line (bolts, nails, screws) (glue?) Whole Surface (glue)	Attention: necessary substructure must be proper in both material and geometry
9.	Lifting/Hoisting of modules for roof installation.	Small modules. In-situ installations using low-tech methods.	Due to lack of lifting equipment, design of PV integrated building element should provide for manual or low-tech hoisting of the elements
10	Moisture	Module edges must be properly sealed.	
11	UV stability	Check UV stability of cells, and seals in modules and other exposed areas.	UV stable materials are now commercially available.
12	Hailstorms	Use tempered glass modules	
13	Wind stability	Use stronger fixing options	

5.5.5. The Haulage and Hoisting Challenge

The challenge of haulage of large panels of building material and their hoisting into place at the building sites continues to plague many developing countries because of absence of both suitable transport infrastructure such as roads and railways or navigable waterways (rivers and canals).

Haulage vehicles and hoisting machinery are also usually difficult to find or very expensive if available at all. This bottleneck makes delivery of large industrially assembled panels difficult and limits the designers and builders by necessitating the use of small building components that can be easily loaded, transported and hoisted into place on site. This situation is even worse in the Photovoltaics industry where most of the key components have to be imported from abroad and transported over long distances on roads that are sometimes very bad. The following photographs compare the ease of mechanised PV installation in the developed world with the hoisting and transport challenges associated with use large sized PV elements (modules and batteries) usually encountered in low technology conditions prevailing in many rural areas of tropical developing countries. Better mechanisation, although desirable, would involve higher costs, in hiring of specialised hoisting and transportation vehicles together with their specialised operators and PV installers.

Fig. 5.7: Mechanised installation thin-film-on-metal BIPV roof and finished roof [[51]]

The thin film roofing material is a Unisolar "Triple Junction" thin film cells on metal sheets, mounted on a timber substructure. The metal sheets covered with PV material are made long to avoid overlapping problems at joints. Such BIPV roofing materials are easy to install in third world conditions except for the mechanised hoisting bottleneck.

Fig. 5.8: Low-tech hoisting of PV Module and transport of Lead Acid Batteries at the Mbinga Sisters' Convent (southern Tanzania) [[52]]

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[51] www.solarintegration.de/showpic.php?file=uploads%2fpics & http://www.solarintegration.de/index.php?id=15

[52] http://www.sonne-ueber-mbinga.de/fotoalbum.php?start=9 and http://www.sonne-ueber-mbinga.de/fotoalbum.php?start=1

5.6. Typical Scenarios of BIPV in Tanzanian Primary and Secondary Schools

There are several options of Integration of PV in tropical school buildings. In implementing these we begin with one school buildings layout shown in fig. 5.9 (a) selected from the existing standard school building drawings approved by the Tanzanian Ministry of Education *(MoEC 2000; MoEVT 2007 a, b, c)* because that particular layout approximates best with the theoretical requirements for tropical BIPV as explained above this example. The major buildings are elongated in the East-West direction with the main facades facing North or South. The standard classroom block whose floor plan, elevations and basic section are shown in fig. 5.9 (b, c, d) is taken as a typical representative of these major school buildings. This layout of buildings would expose the roof surface (inclined N or S) to the most intense solar radiation for the longest duration per day. Furthermore, it is easy to alter the roof inclinations to suit to optimal tilt as explained above. More drawings of the standard secondary school buildings from the Tanzanian Ministry of Education and Vocational training (MoEVT) are in the annex.

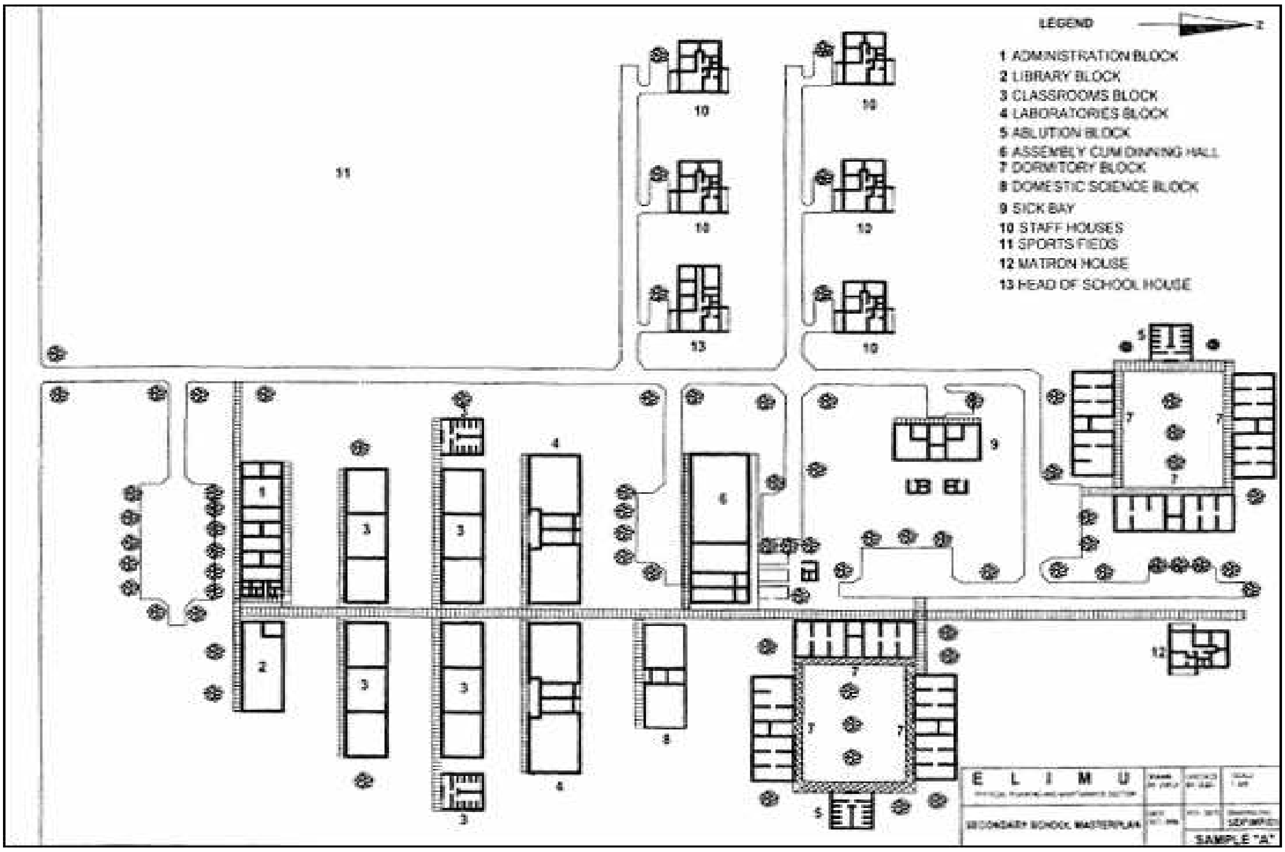

Fig. 5.9 (a): The selected typical standard secondary school site plan in Tanzania considered appropriate for BIPV ***(MoEVT 2007)***

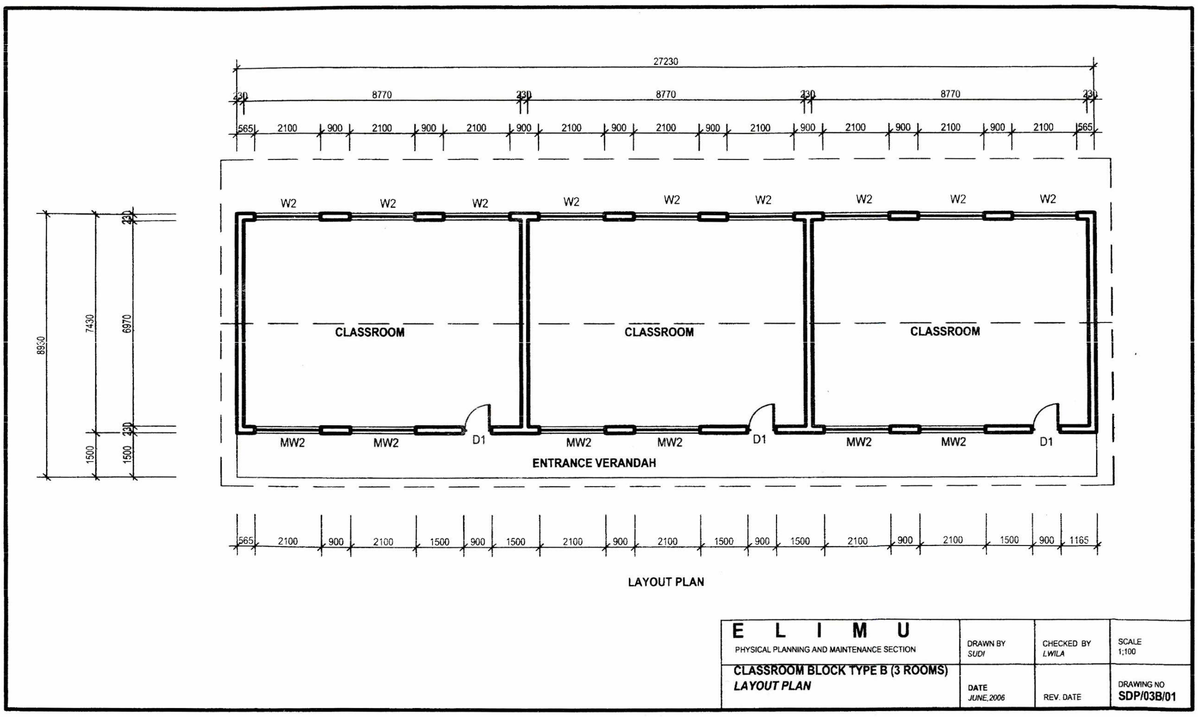

Fig. 5.9(b): Typical classroom floor plan from standard secondary school drawing provided by the Tanzania Ministry of Education and Vocational training (MoEVT 2007)

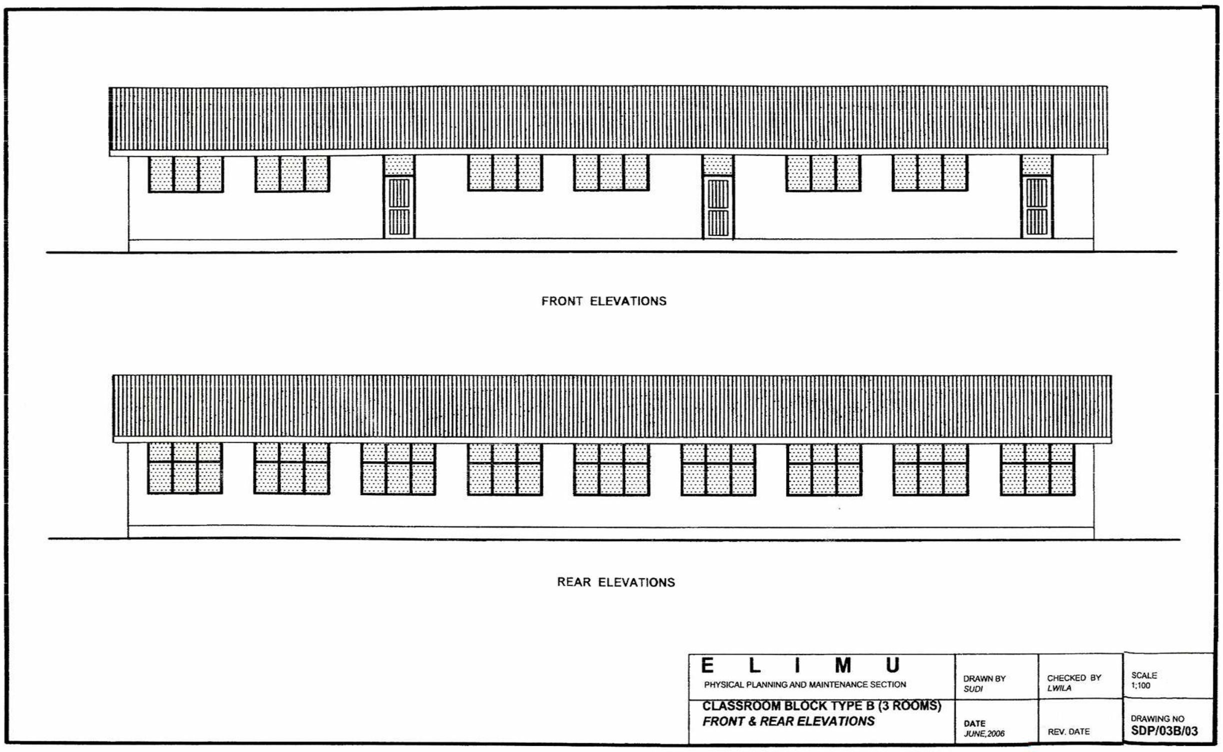

Fig. 5.9(c):Front and rear elevations of the typical classroom block in standard secondary school drawings by the Tanzania Ministry of Education and Vocational training *(MoEVT 2007)*

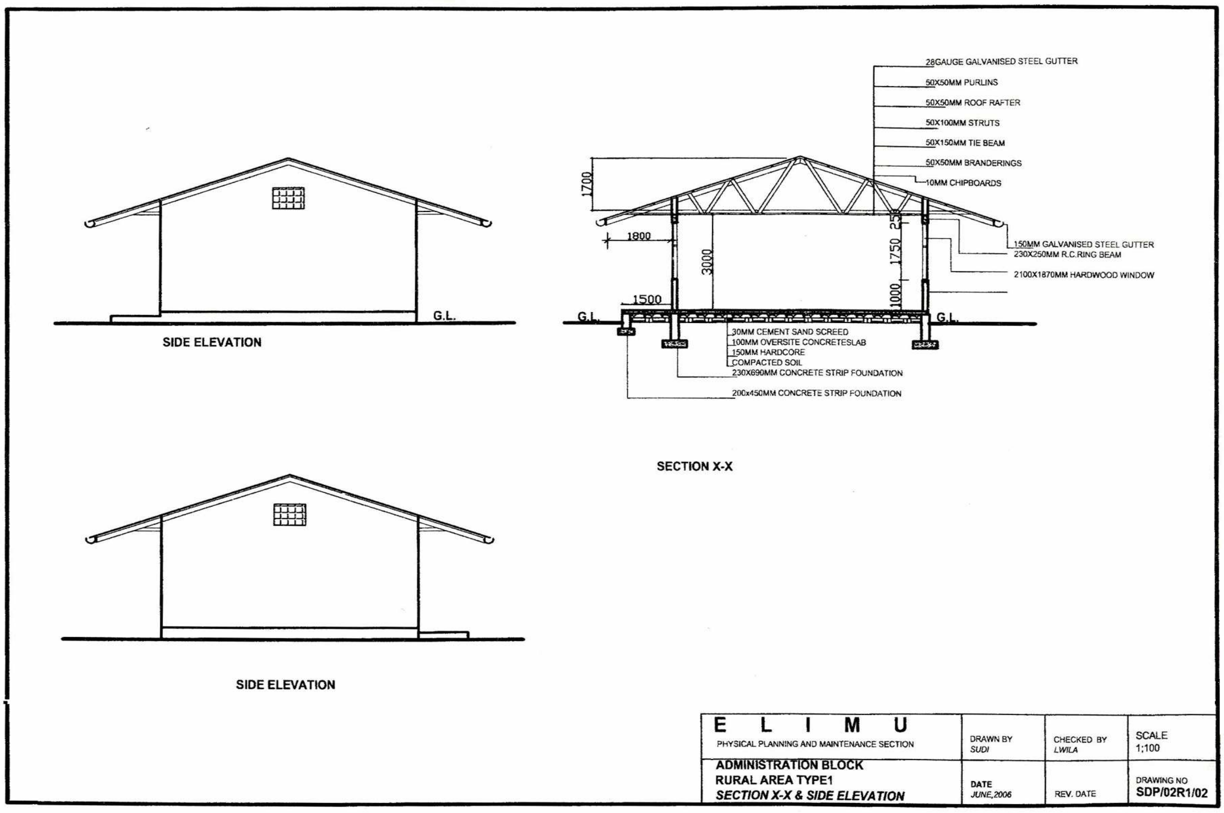

Fig. 5.9(d):Side elevations and basic section of the typical classroom block in standard secondary school drawings by the Tanzania Ministry of Education and Vocational training *(MoEVT 2007)*

5.6.1. Developmental alternative Scenarios for BIPV roof design

Based on standard educational buildings designs of the Tanzanian Education Ministry and the selected school compound buildings layout, various versions of possible BIPV roof designs for the same standard plan drawings are presented. The standard roof slope inclination of 25^o, however, is not the optimal one. Installation of PV modules on such a roof without modifying their tilt angle, while elegant looking, will actually have the modules working in suboptimal conditions (delivering electricity below maximum capacity). In order to improve the situation, the alternatives would be to set up the modules on the roof at optimal angle. This can be achieved by installing the modules at optimal tilt without changing the roof slope but the solution has a bad architectural appeal on aesthetic grounds. A better solution would be to modify the roof to optimal slope and either fix the modules on top as usual or to integrate them into the roof fabric itself as described earlier. The latter option gives the designer room for various architectural manoeuvres in roof design for tropical BIPV. A more detailed description of the options is described hereunder.

5.6.2. The traditional way: Setting up PV modules on the existing roof following the same roof profile.(inclination and orientation)

In this scenario the PV modules can be mounted directly on the existing roof using timber support following the same general inclination and orientation of the roof. In this scenario, several module layers may be installed on the same roof slope or on several roof slopes, depending on relative sizes of modules and roof as well as addressed energy demand

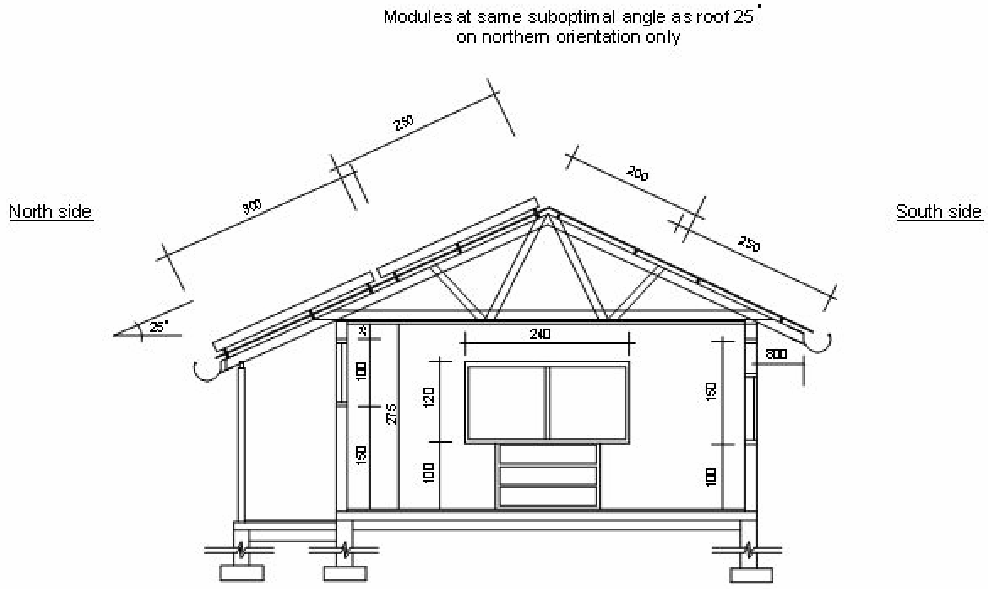

Fig. 5.10: **Scenario 1: Modules mounted one side of an existing roof, following the usual roof inclination. (In this case whole installation can work as one array)**

The advantages of this scenario are ease and speed of installation. There is very little design and modification work to be done. The other advantage is maintenance of architectural harmony between the initial roof and PV modules. The disadvantage, however, is that, although there will be electricity generation, one cannot guarantee best performance of the PV modules. Everything depends on the initial roof inclination and orientation: if the original roof inclination and orientation are not optimal then there is little possibility for optimal electricity generation. In the case of mounting of PV panels of several differently oriented roof slopes, in addition to the suboptimal electricity generation, modules on each slope work as different arrays with similar modules under similar conditions generating differently i.e. similarly rated modules under similar solar conditions generate electricity at different electrical parameters and so must be wired separately. In the example depicted hereunder, were the installation to be made in Dare s salaam, Tanzania, the modules mounted on the Southern oriented roof slope would produce less energy annually compared to their equivalents on the Northern oriented slope although in some months within the period corresponding to the Southern summer (Northern winter) they may perform better than their Northern inclined counterparts.

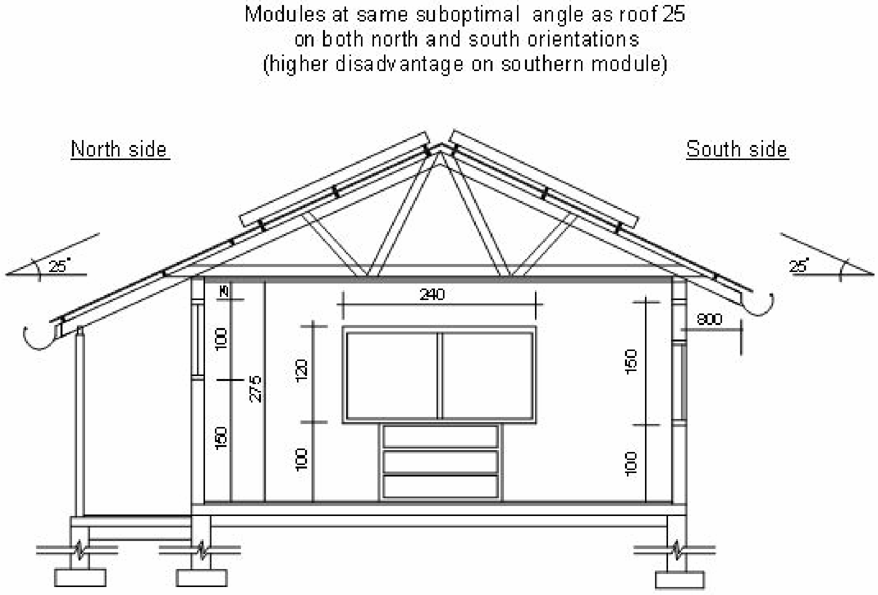

Fig. 5.11: **Scenario 2: Modules mounted on several sides of an existing roof, following the usual roof inclination (which is usually not optimal for PV)**

5.6.3. The modified traditional way: Redesigning the whole roof to optimal inclination and setting up PV modules on it

In this case the roof carrying trusses are modified so that the whole roof will itself have its inclination within the optimal range of angles. It is then roofed with the usual roofing material (usually corrugated metal sheets), then the PV modules are mounted on top. The result is practically a double roof, in which the PV modules form the top roof while the original roof remains under. This method has the advantage of solving several practical problems and enabling the whole roof or most of it to be used for mounting of solar modules. The gap between adjacent PV modules need not be watertight because that problem is taken care of by the real roof underneath. So there would be no water leakage problem. The modules can themselves be fixed more easily with a few bolts, using bolt- &-cap method, where the bolt goes through the gaps between adjacent modules while the cap holds the two adjacent modules in place (see Fig.5.13 and 5.14 below). The main advantage of this set-up is that the whole roof or most of it can be used to mount PV modules. The mounting structure will have the least cost.

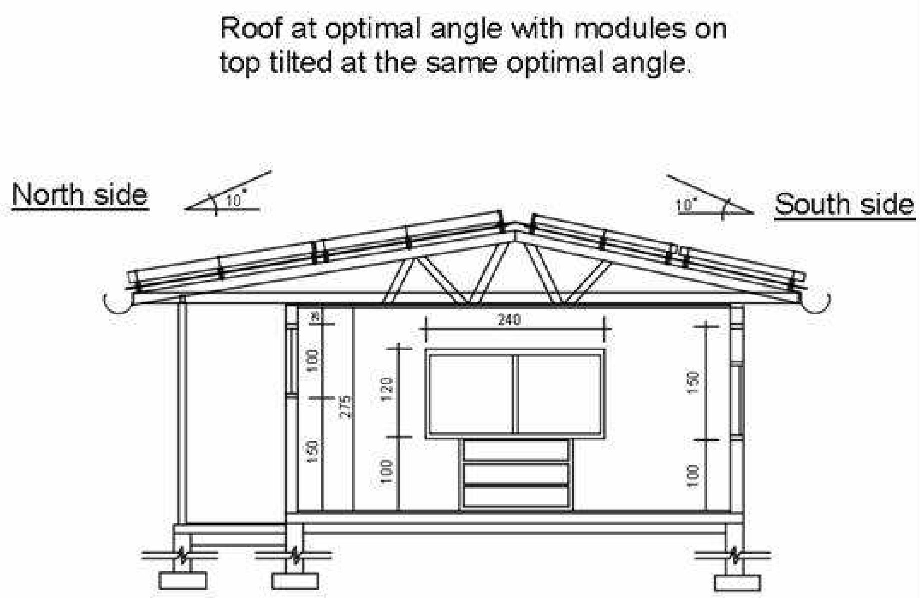

Fig. 5.12: Scenario 3: Roof set at optimal inclination and mounted with PV modules (This diagram shows mainly the mounting principle)

Fig. 5.13: Double roof at quasi-horizontal mounting of rimless PV modules (note the utilisation of the whole roof for PV module mounting) [[53]]

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[53] http://www.solarintegration.de/index.php?id=15#

5.6.4. PV modules on an existing roof but at an inclination and orientation different from those of the roof.

In this scenario although the roof may have other (suboptimal) slope and orientation parameters, but the PV modules are set on it at optimal tilt and orientation. Such a case is resorted to by some installers just in order to optimise the annual electricity gains without caring about the architectural harmony between the existing roof and the retrofitted PV modules.

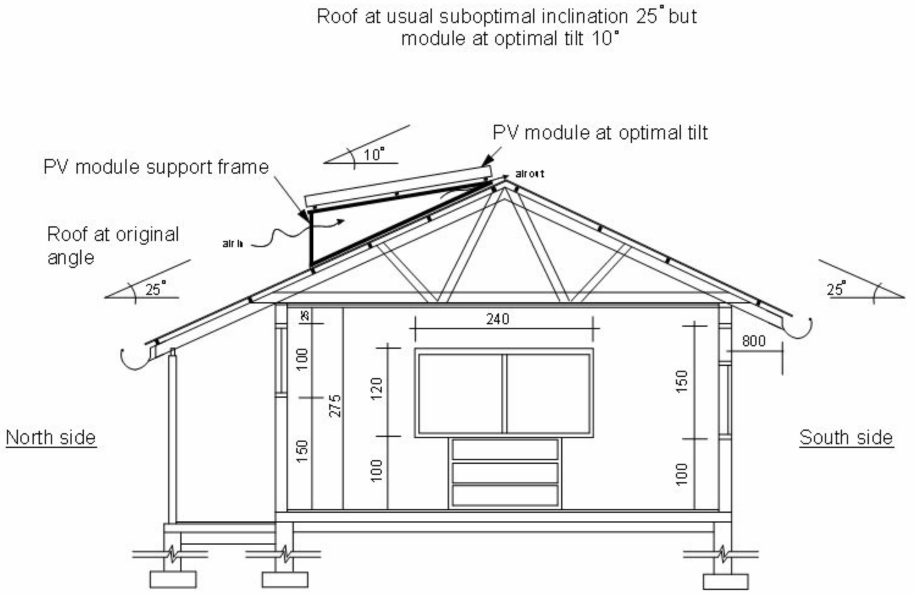

Fig. 5.14: Scenario 4: Roof at old (suboptimal) angle (25°) with PV modules mounted at optimal tilt (10°)

There are many examples of this architecturally unpleasant situation with the main argument in its favour being only to maximise the solar gain benefit from the retrofitted PV installation on a pre-existing building while avoiding extra costs associated with dismantling the whole roof and rebuilding it with optimal slopes. A few examples have been noted at:

- The Uganda Revenue Office building at Tanzania–Uganda boarder post at Mutukula, on the road between Bukoba (TZ) and Masaka (UG).
- The laboratory building at Katale dispensary in Bukoba District, N.W. Tanzania owned by the North-Western Diocese of the Evangelical Lutheran Church, of Tanzania, (ELCT-NWD)

5.6.5. The new way: Roofing with PV modules only

This scenario involves actual integration of the modules into the roof itself, thereby **replacing** the top cover of the roof with PV modules. This may take place over the entire roof or just over a part of it. In this case in addition to generation of electricity the PV modules must take over all roof cover functions at least for the part where they are installed. It should be noted that for optimal electricity generation, the module layout is best horizontally placed, but for other roof functions such as protection against rain and leakage, a slope is necessary. So as a compromise solution between the two needs in form of a gentle roof slope is preferred. The exact value of the actual maximum inclination angle of a roof incorporating built-in PV modules depends on the locality and the orientation of the slope. It can only be estimated after considering annual solar gains by exact calculations or computer simulation. There are many simulation programs for such purposes and PVSYST is just one of them. According to the results of the PVSYST simulation for Dar es Salaam, as has already been indicated before, for best electrical results the best slope inclination angles have been shown to be a maximum of 15° inclination towards the North, or a maximum of 10° in all other orientations. With PV modules alone making the outer shell of a roof inclined at angles there arises a danger of roof leakage that must be avoided. To accomplish this task the following roofing styles are to be encouraged:

5.6.6. BIPV Roof Constructions with Single Module Spans

BIPV roof constructions with single module spans, is done in order to avoid top-down joints between modules, which would pose a threat to water tightness in an almost flat roof, especially in low-tech conditions prevailing in third world rural areas where these schools would be built. The side by side joint between adjacent modules can be easily covered by a metal cap that would double as a device for fixing modules. The best and most effective single module roof spans may, therefore, be achieved if either the roof span in question is short enough to be covered by a single standard module, or if it would be possible to have special modules specifically manufactured for the purpose. The latter option would be rather expensive in terms of manufacturing transportation and installation costs, especially in low mechanisation conditions prevailing in most tropical third world countries. Therefore, this option is unsuitable for most cases of 3rd World tropical BIPV.

5.6.7. BIPV Single Module Span Roof Constructions Using Standard Off-the-Shelf Modules

From the foregoing section, it is seen that the best option is to use standard, off-the-shelf PV modules available on current PV the market. In such a case, one may still have the following sub-options:

- **Single module wide veranda coverage:** In this case, the veranda or passageway frontage of main school buildings is covered by PV modules, leaving the main roof in its traditional style. The main advantage of this type of standard module use, is that it is possible to set the gradient of the PV modules at optimal tilt while leaving the main roof at the traditional steeper inclination. This enables the combination of BIPV modules with such building materials as traditional roofing tiles, slate shingles etc., which may in some cases be easier to find or prepare within the vicinity of the school in question. The main conditions for mounting of utilizing PV modules as veranda cover are:
    - The availability of modules long enough to exceed the width of the veranda in question.
    - The PV covered veranda roof must **not be vertically separated** from the main roof. This is necessary in order to avoid seasonal PV module shading from the main roof, due to solar declination. This problem is graphically presented on Fig.5.15(b).

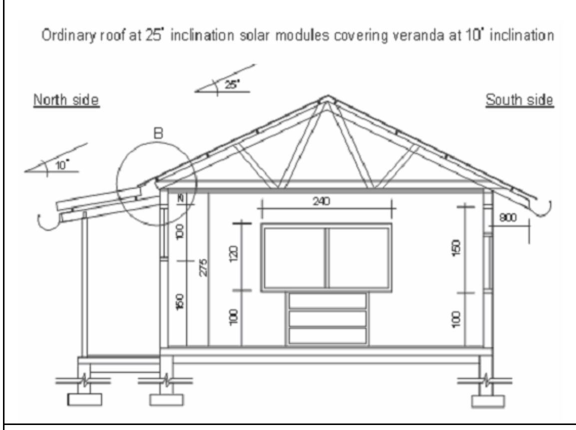

Fig. 5.15(a): PV module roofed walkway/veranda (correctly installed)

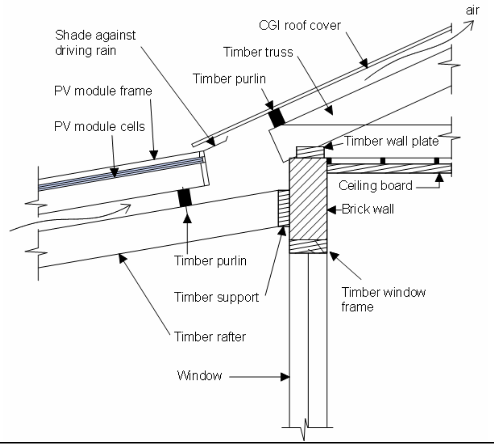

Fig. 5.15(b): Junction of veranda PV module and main roof (Detail B)

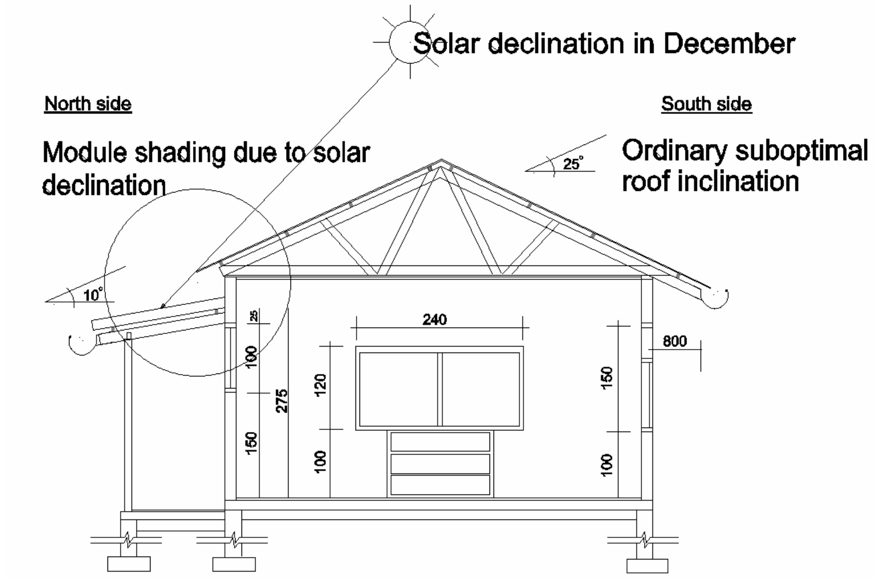

Fig. 5.15(c): **Wrong installation: vertically separated veranda roof may cause partial shading of PV modules due to seasonal solar declination.**

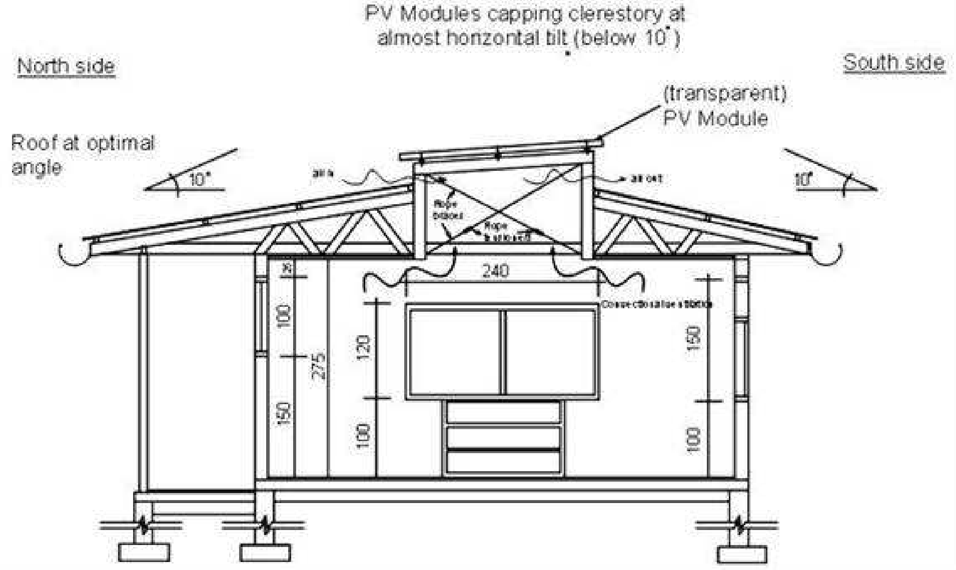

Fig. 5.16(a): **Single span clerestory using standard straight PV modules (the Roof Cap PV module row may be made for seasonal manual solar tracking.)**

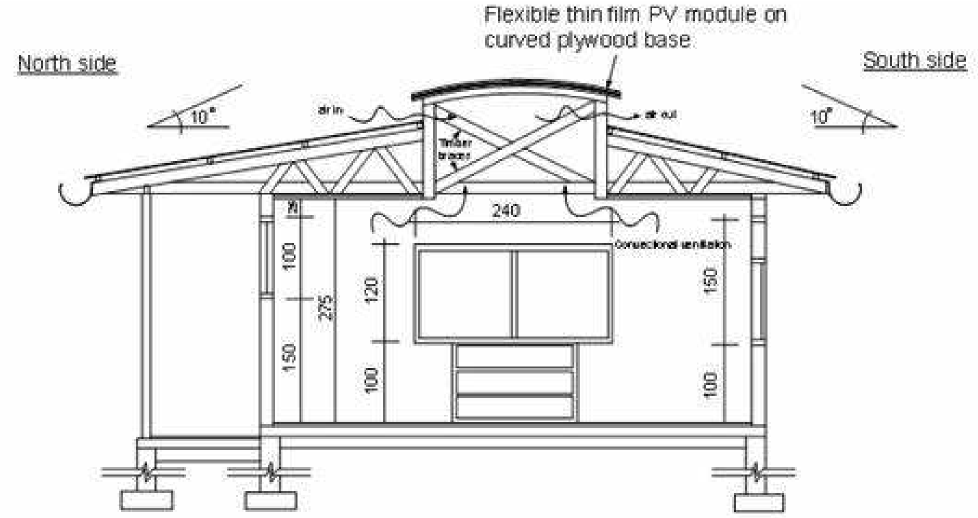

Fig. 5.16(b): **Single span clerestory using curved PV modules (usually thin film PV material on a flexible substrate)**

- **Single module wide clerestory coverage:** The other alternative of using standard "off-the-shelf" PV modules for integration in quasi-horizontal roofs in Tropical BIPV, is to have one module wide clerestories on roofs. In this case the slope of the module can be made almost horizontal or can be made to tilt seasonally for optimal solar gain (seasonal solar tracking). Seasonal solar tracking can be made manually at frequencies from once every three months to once per month. Alternatively thin film PV modules on a flexible substrate can be installed onto a curved roof-cap clerestory. In both cases, in addition to electricity generation the installation can also aid in the ventilation of the classroom below. In addition classroom illumination can be improved and modified if transparent modules are used

5.6.8. Roof constructions with optimal installation of two rows of modules (The Two Module Span across a roof cap)

Optimized roof inclination enables roof integration of PV modules in any orientation without loss of electrical gains potential. In this case PV modules can really integrated into roof replacing some of the top outer membrane provided care is taken to avoid water leakage or ingress. For a two module wide PV installation, this limits such optimal installation to be carried only on the topmost roof level with the modules sloping in opposite directions and their top covered by a cap. Such an installation, however, is best practicable only with a new building or a complete roof replacement in case of an older building.

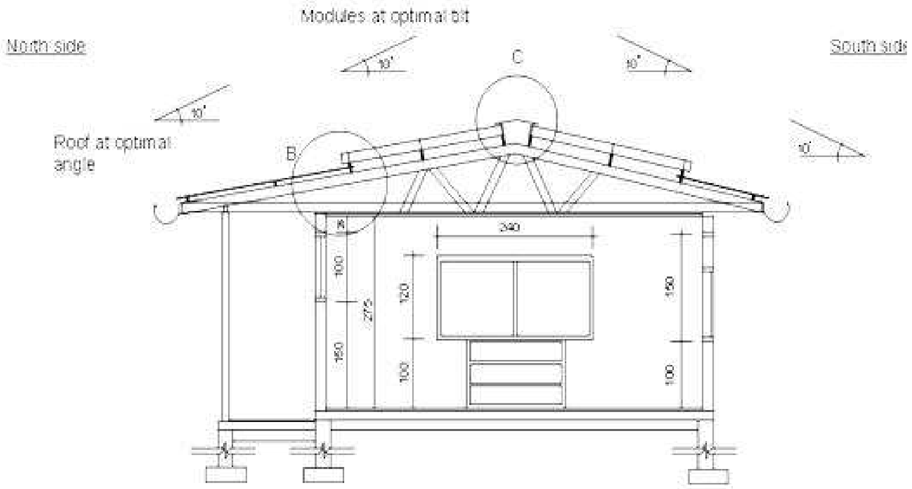

Fig. 5.17(a): **Optimized integration of two rows of PV modules**

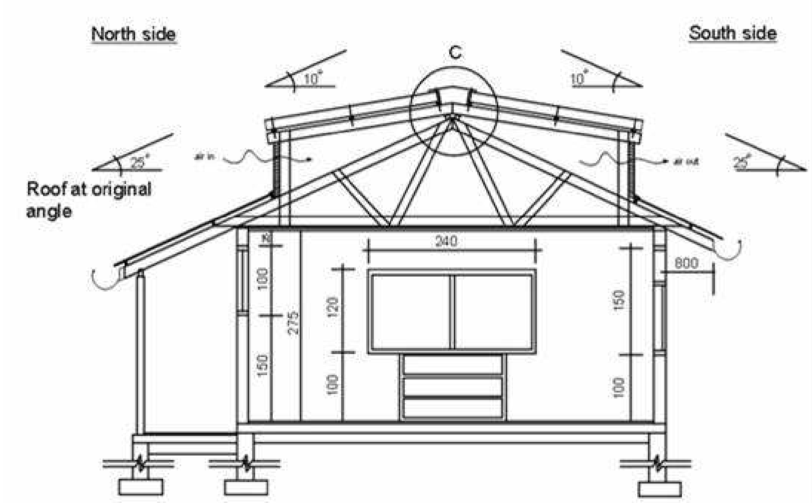

Fig. 5.17(b): **Two PV modules optimally placed on clerestory spanning across roof cap (or mid ridge)**

If, however, a decision to **retrofit an existing building** with BIPV is taken, but for any (mainly economic) reasons a complete roof replacement is not possible, then a second best alternative would be optimal PV module installation on an additional clerestory with only partial roof cover replacement as seen hereunder. This solution would also enhance ventilation both for the building and the modules. It may also improve internal illumination if transparent PV modules are used. It should be noted here, that in both cases, careful and proper attention in installation of the roof cap is key to success of the roof

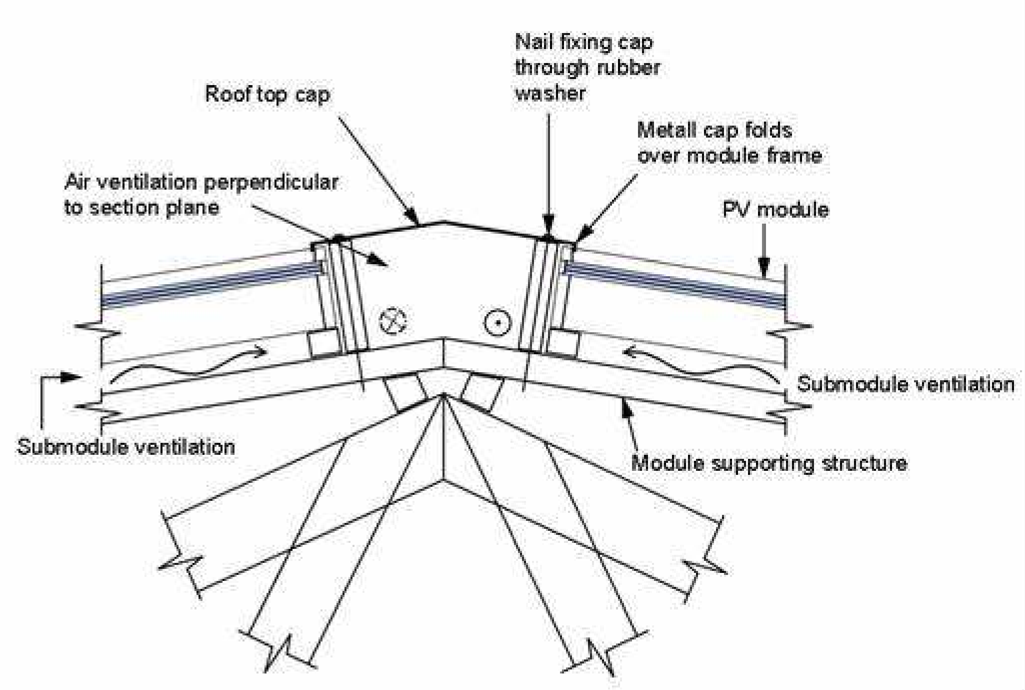

Fig. 5.17(c): Roof Cap detail: The roof cap (C) is a key element for success of a two module wide BIPV arrangement without any lower watertight roof membrane
(Note: Air movement under the cap follows the roof ridge)

In Fig 5.17(b), despite the suboptimal original truss, the clerestory mount of the PV modules offers several advantages. There is no water leakage problem because the modules are capped on top and sloped in opposite directions. In this case the modules are really roof integrated and actually do replace the original roofing material over the area they are placed. Moreover the clerestory offers a good ventilation opportunity for the PV modules. However the roof parts below the clerestory remain at the original steeper angle. The main disadvantages of such a roof construction include high consumption of roof structural material and complication of construction, both of which tend increase the roofing cost.

5.6.9. Multi-module span constructions

In principle, it is possible to have quasi-horizontal roof slopes covered with several rows of PV modules along each slope. However making the modules alone double as the sole roof cover pauses special problems and demands special solutions as follows

- **With sealed or module overlap**: In this case special modules must be specifically meant to overlap. The top part of each module (meant to go under next higher module row) may have either “dummy cells” or no cells at all. To prevent water leakage in case of rain, the overlapping PV module parts may be glued together (sealed) with help of a special water-tight sealing material such as special silicone that will form a flexible joint allowing a degree of relative movement of the modules but that will withstand high ultraviolet radiation levels over a reasonably long time. This seal material must also allow subsequent re-application on a previous layer without much trouble. In addition the top and bottom of the whole sealed ensemble must be open to the atmosphere to aid ventilation of the solar cells, in order to keep them cool under intense tropical solar radiation.

- **With open module overlap:** Open overlap has the same demands for the PV modules (no cells or a layer of dummy cells) except that this time the modules are not sealed to each other. They may desirably have gaps between them to aid ventilation. While such an arrangement may work well for steep slopes, it will be more difficult to achieve water tightness in quasi-horizontal roofs. In such situation a broader overlap may be required which may prove to be waste of precious PV module material, even without cells. (Module glass is usually more expensive than ordinary glass). Otherwise, a watertight membrane or water channels must be applied under the PV module joints or gaps.
- **With under roof watertight membrane**: To solve the water tightness problem a layer of watertight membrane may be required under the PV modules, but such material is usually very expensive and requires a higher level of roof preparation both in terms of materials and technology. Although that is generally a hi-tech solution, which may prove to be relatively more expensive in tropical third world conditions, it is nevertheless worth a try especially when the building under consideration is of a high value investment nature.
- **Back to tradition: PV modules on an existing optimally inclined roof:** This seems to be the most practical way, especially for large buildings, such as assembly halls, warehouses such as is depicted on the Coca-Cola house below:

Fig. 5.18:PV Modules on top of an existing roof

Fig. 5.19:Labour-intensive manual preparation of thin film PV sheet for roofing.

5.6.10. Thin film BIPV Roof modules on flexible substrates and rigid substructures

In such roofs, an outer cladding of a flexible tarpaulin-like light sensitive composite membrane material is applied on a specially prepared roof substructure. The light sensitive material on that flexible composite membrane is, in fact, a series of thin film PV cells that had been previously applied it. These are the thin film PV modules. They can just be glued on the specially prepared substructure (under-roof) covering the whole roof or for just part of it. The water-tightness problem is solved by simply having them glued to overlap or using long module strips as seen hereunder. **The under-roof may be made of some cheaper material not usually used for external roof cover purposes, e.g. plywood sheets, chipboard or tongue-&-groove (TNG) timber boards.** Although thin film modules (at least for those already currently on the market) have generally lower efficiencies compared to their more rigid mono-and polycrystalline cousins, they are comparatively less temperature-sensitive and much cheaper in cost per watt terms. The major work for their installation is the cost of the special roof substructure preparation and they require more careful installation.

As such they are more **labour intensive**, a characteristic that makes them more suitable for application in Third World countries where labour is still cheap. Finally, such a roofing system has the advantage of giving the architect some leeway to work with PV on roofs of different shapes, both curved and straight. (See the example of the Architecture Building at Ardhi University Tanzania, described in the next section). It should be noted that for the best result, the tangent to the roof curvature should remain within the optimal limit (i.e. < 10° for the E-W curvature in Dare s salaam).

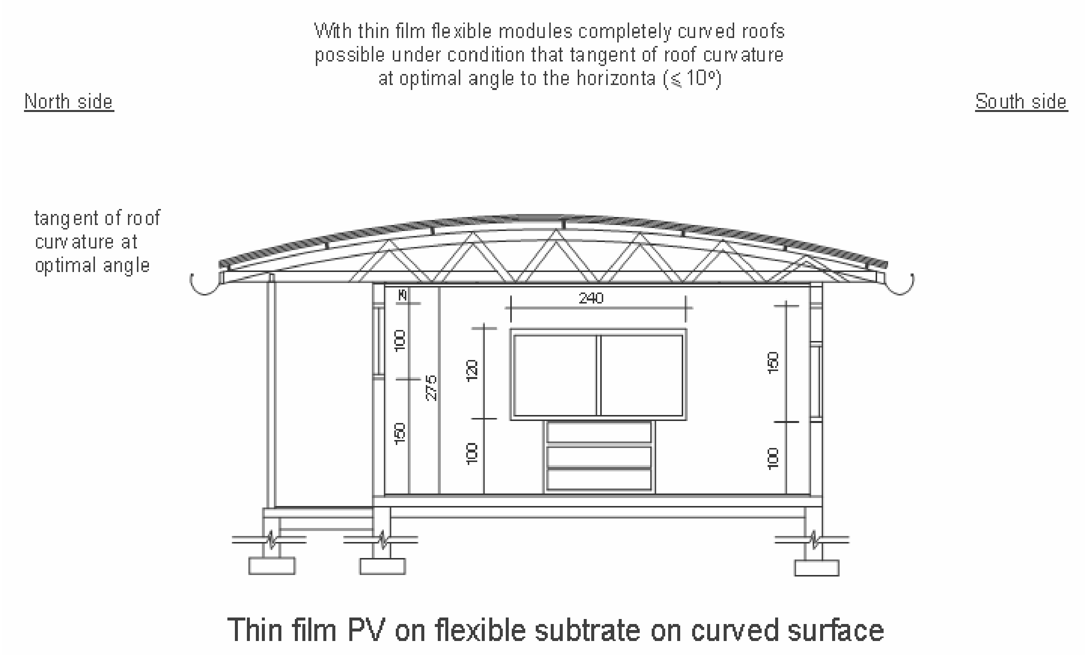

Fig. 5.20(a): **Thin film PV sheets on a curved surface covering the whole surface (suitable for the Architecture Building of Ardhi University, Dar es Salaam, Tanzania)**

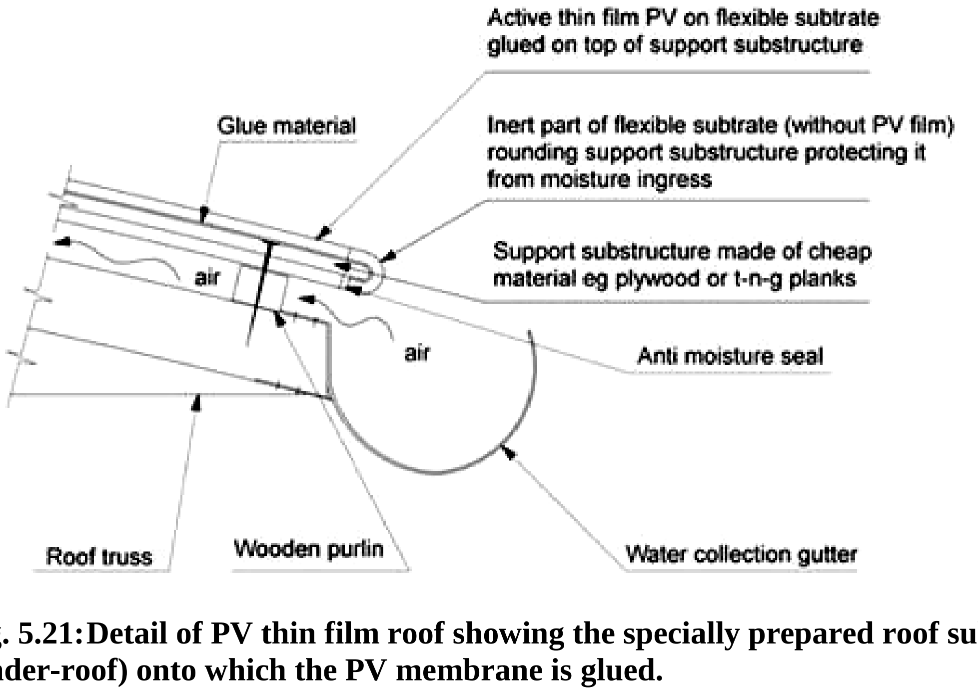

Fig. 5.21: **Detail of PV thin film roof showing the specially prepared roof substructure (under-roof) onto which the PV membrane is glued.**

5.7. Possibilities of BIPV in Large Tropical Buildings: examples of some Tanzanian University Buildings

Large tropical buildings, e.g. offices and academic buildings of Higher Learning Institutions (HLI) do offer great opportunities for demonstration of BIPV as follows hereunder:

Fig. 5.22: Ardhi University Roofscape, showing Solar Roof Candidate Buildings (i.e. buildings with Solar Roofing potential)

5.7.1. Solar Roof Candidate Buildings at Ardhi University (ARU)

Some of the buildings at Ardhi University (ARU), Dar es salaam, Tanzania, for example, can be refurbished with different kinds of solar roofs. Fig.5.19 shows the ARU roofscape with buildings in the foreground that certainly need new roofs because the existing asbestos-cement ones with must be changed for public health reasons. This is a good opportunity for putting up BIPV roofs to replace of the undesirable asbestos-cement.

The buildings' orientations, elongated in the E-W direction, do offer a good opportunity for PV integration. Moreover, in their current use, with offices, laboratories and computer labs, the appropriate load for the PV is also ideally located under these roofs, thereby minimising energy losses due to long distance electricity transmission. Many types of modules would be suitable for them. It is, therefore, proposed that each of the 3 buildings be fitted with a different type of PV modules for academic purposes, field testing and module comparison purposes. In the middle ground, with its curved roof and correct E-W orientation, the Architecture building, is another candidate for integration of thin film PV modules on flexible substrates.

5.7.2. Solar Roof Candidate Buildings at Dar es Salaam University (UDSM)

The main Building of the College of Engineering and Technology (COET) at Dar es Salaam University (UDSM) main Campus, offers another opportunity for BIPV. According to studies conducted in 2003 and 2004 by a joint group of Engineering and Architecture students from the Universities of Dortmund and Dar es Salaam, under the co-supervision of this author, the current roof was seen to be in need of replacement and several versions of multipurpose solar roofs incorporating PV, solar thermal, daylighting and rainwater harvesting were proposed. Fig. 5.20 shows the current roof and Fig. 5.21 is one of the proposed versions submitted to the MONDIALOGO competition.

Fig. 5.23(a): The COET main building with its old roof (as it looked in 2004)

Fig. 5.23(b): The same building with the proposed BIPV roof

During the same exercise, energy demand of the building that could be satisfied from the proposed BIPV solution was calculated and is presented in Table. 5.2 hereunder:

Table 5.2: Summary of annual Energy demand in kWh/a for Lighting and ICT at the COET Main Building at Dar es Salaam University Main Campus.

		old lights	**new lights**
Lighting	Office working spaces	23,018.40	7,672.80
	Lecture halls	120,772.40	40,240.80
	Computer pools & Tutorial rooms	38,651.04	12,886.68
	Circulation areas	114,383.70	38,127.90
	Service areas	11,037.60	3,679.20
	Area under new roof	84,852.60	28,284.30
	Total Lighting Energy	**392,715.74**	**130,891.68**
ICT	Staff offices	65.220.00	
	Computer Pools	158.280.48	
	Total ICT Energy	**223.500.48**	
Total Energy demand		**616,216.22**	**354,392.16**

Summary of Chapter 6: Under this chapter, a general description of sources of finance for PV projects is presented and proposals for realisation of the particular project examples described in chapter 6 and 7 are presented and discussed.

6. ECONOMICS (FINANCING and PAYBACK) of PV INSTALLATIONS

6.1. Background information

Issues of financing of PV projects have been discussed by many authors including *Heidenreich (1996)* in her article “Seeing the Light: Solar PV in East Africa”. Most of the available literature about financing PV in Developing Countries including Tanzania e.g. *Gabler (2004)*, aims mainly at small scale domestic applications in domestic households. In some PV market development studies intermediate beneficiaries, such as wholesale dealers and sub-dealers, or non-governmental organisations, have been brought into the picture, only as volume facilitators in order to tap into the domestic consumer market with more ease due to better economies of scale. In all these PV market development studies the domestic household and its needs, mainly lighting, radio and TV broadcast reception, have always been the centre of focus.

This thesis, however, deals with PV for institutional application in government services, especially in the three selected areas of education, healthcare and public administration. Here are fundamentally different energy demand patterns both in timing and scale of operation. In public administration, for example, many small scale daytime demand centers, widely spread in many villages over a very wide area are observed, with the main PV electricity demand powering information management and delivery instead of lighting, the traditional requirement in domestic applications. In education and healthcare, daytime needs are also predominant although lighting may also be a requirement in some aspects of night operation. In boarding secondary schools, for example, in addition to daytime requirements, intense lighting is required for part of the night during evening study sessions, whereas less intense and/or intermittent lighting may be required for the rest of the night in dormitories and other areas related to students’ residential areas. Similarly, in rural dispensaries, intermittent intense lighting may be required in operational areas such as patient reception areas, or labour and delivery rooms with less intense nightlong lighting in patients’ wards. Thus these institutional requirement patterns differ significantly from domestic requirements. In such institutional projects, however, there may also be elements of domestic applications of PV, but in most cases these will mainly be dealing with domestic lives in the households of workers of the public institutions or projects in question. The financing of such domestic PV applications, can therefore, either be treated as part of the institutional PV applications, or as domestic PV applications in the usual way.

The developing country focus also brings in a few important differences that one has to note between financing of energy projects in countries with developed economies and financing of seemingly similar projects in developing countries. One of such differences is the question of power concentration i.e. relative power demand (and therefore sizes) of individual energy demand points in each group of countries. The energy demand per point of project location in a developed country is much higher than that of a project location in a developing country. The other difference is the prior existence of the necessary energy infrastructure in the former countries (with developed economies) and absence of such pre-existing infrastructure in the latter (developing countries). In the former group of countries (developed) the financier has a choice of whether to deal only with questions of power supply to the existing infrastructure, which may sometimes be old and, therefore, inefficient technology, or in addition to power supply additional investment may be required to refurbish the pre-existing old technology energy infrastructure in order to render it more efficient. In the developing countries, however, most often there is no pre-existing infrastructure. The financier therefore has to finance both the energy consuming infrastructure (load side) and the energy technology itself, e.g. PV in this particular case. This situation gives both certain challenges and special opportunities. On the positive side is the fact that there is an opportunity to opt for the most modern and, therefore, most energy efficient infrastructure technology and also to be able to match the energy supply to the envisaged load, directly from the start. The main challenge is that the capital layout per unit of energy resource to be supplied may be very big because of the additional capital outlay for the basic infrastructure, but there is little or no other option at all. In most cases there is no pre-existing old infrastructure to use. To illustrate the point one may consider ICT. In Europe, for example, one already has old telephone systems and computers in place which may or may not be improved or modernised before being powered by new energy resources e.g. PV, but in Africa, in order to be able to power ICT using new energy resources such as PV, one has to finance both the PV system (modules, controllers/modifiers and storage) and the supply of wireless cellular phones and/or computers and associated peripherals. In some cases setting-up or extension of a (usually recently installed modern) communication network may also be necessary. Such a situation in developing countries, therefore, demands innovative approaches from both financiers (such as local and foreign bankers) and state authorities who are usually policy makers, controllers and regulators of financial, communication and energy institutions.

From the banking point of view, financing of any project partly depends on the project size, i.e. required amount of money for the project and partly on its form of ownership. These two factors among others influence the capital layout and financing conditions. In case of a PV electrification project, the amount of money required is also influenced by the expected loads which influence the types, sizes and quantities of PV equipment required. Although project costs fluctuate depending on the above named factors and other external issues such as required execution speed (i.e. emergency or normal deployment) project location and competition, a price index for key inputs into a project, however, serves as a good point of orientation from which one can judge the expected project costs or bargain for reasonable project cost reductions. As a bargaining aid it is very important to Table 6.1 below, gives the latest price index for key PV system components as recently surveyed by [54].

Table 6.1: Price index for various PV components. [51]

ITEM	PRICE UNIT	UNIT PRICE	
		Euros	**US Dollars**
PV modules (polycryst)	€/Wp (US$/$W_p$)*	4.71	4.83
--Thin Film	‘’	2.36	3.68
Batteries	€/Wh (US$/Wh)**	1.31	2.04
Inverters	€(US$)/$W_c$	0.462	0.722
Charge controllers	€/A (US$/A)	3.75	5.86
	€/W ***	0.312	

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[54] www.solarbuzz.com

Key: W_p = Watt-peak. (For rating PV modules = power at standard test conditions)
W_c = Watt-continuous (unit for rating inverters= power at continuous work)

Additional Note:

* The Euro and dollar price index for PV modules has been calculated separately for Europe and America reflecting local markets, whereas for other items the price index in both currencies is based upon global market prices and prevailing Dollar/Euro exchange rates. In addition, given prices for thin film modules are the lowest.

** Usually batteries are rated in Ampere-hours (Ah) at various regimes of operation. This price index however, is given at a Watt-hour (Wh) rating for various types of batteries calculated for a standard discharge of 20 Ah.

*** €/A converted into €/W for a 12 V DC storage system.

As stated further above, for projects in tropical developing countries electric load components must also be incorporated in any system costing because they are usually initially missing. In the special interest areas selected for this thesis, namely education, healthcare and public administration, the typical loads will mainly include ICT system components such as computers (preferably laptops), their associated peripherals and network components. Cellular telephones, though usually associated with personal use, could also be used in rendering public service especially in matters pertaining to quick information delivery services such as progress reporting, measurement results and statistical data transfer in public and health administration. They are also useful in police communication but that is outside the scope of the current thesis. Other electric load elements in the selected public services will be lamps and lighting systems but only in those services that are expected to continue operating even after sunset. Such services will mainly be found in upper educational institutions (from secondary schools onwards) and in all healthcare systems. Electronic diagnostic tools and refrigeration systems are expected to feature only in the healthcare system. Although other electronic items such as radio and TV reception may feature in education systems, they will mainly be in use in domestic dwellings of people manning all these public services, just as for the general public. Although a price index table for those electric load elements is desirable, the price shown hereunder can only be valid for a short time because of increasing product energy efficiency due to technological improvement and lowering unit prices due to production innovations. Although in some cases higher product demand may tend to increase prices and price indices for some products, e.g. PV modules, currently tends to stabilise and sometimes increase the price index of some products (eg PV modules) th general tendency is still towards lower prices. The current (August 2008) price index for system load components is presented in table 8.2 hereunder.

Table 6.2: Price index for typical PV electric loads expected in the selected government services

ITEM	TYPICAL UNIT POWER (W)	PRICE	
		Per item piece (€)	Per Unit power (€/W)
Computer systems			
--Laptops	100	500	5.00
--Modems	100		
--Routers	12	40	3.33
--Hubs			
--Switches	4.5	20	4.44
--Printer/fax/scanners	30	300	10.00
Lighting appliances			
--CFL	10-15	10-15	1.00
--LED*	5	30	6.00
Cellular phones	2	60	30.00
Refrigeration Unit			
--compression cycle	60	670	11.17
--absorption cycle	47	130	2.77
Radio Receiver	12	40	3.33
TV receiver			
-- LCD Color 14”	48	185	3.85
--USB computer add-on	1.5	30.00	20.00-
--B&W	-	-	-

***Note:** LED lamps, though much more energy efficient than compact fluorescent lamps (CFL), currently available commercial units are half as bright but still six times more expensive than the CFL units they are supposed to replace. Therefore, LED based lamps should be used in very low power systems, e.g. USB LED task lamps for notebook computers, small flashlights (pen-lights) or in conditions where clear vision is not quite necessary such as in “way-markers” for staircases, corridors or passageways; or in circumstances where the need for energy efficiency far outweighs purely economic considerations.

6.2. Financing of PV in the Education System

Taking the Tanzanian Educational System as a typical example, we see that different levels of institutions in the education system have not only different ownership patterns but also different scales of energy and especially electricity requirements. This double situation calls for different financing strategies for different levels within the education system of one and the same country. As seen earlier the Tanzanian main educational system is divided into four main stages, namely: Pre-Primary, Primary, Secondary (Ordinary and Advanced levels) and Tertiary, with several off-shooting branches into vocational training, sub-professional and semi-professional training departing from the main line at different levels especially after primary school. Efforts are currently underway to upgrade first of-shooting level to come only after at least ordinary level secondary school. The different school levels and offshoot colleges have different forms ownership patterns and varying electric load characteristics, which may influence financial decisions in the quest for electrification of the educational system. In some rural primary schools, direct stand-alone PV may be the best option, whereas in some secondary schools and vocational training centers, a choice may be considered between purely stand-alone and hybrid PV systems. In the current absence of feed-in laws and tariffs, a hybrid system incorporating both mains grid and PV may be introduced in some cases where institutions are near mains grid only for power security reasons, whereas more remote areas, a predictable but irregularly fluctuating load may lead to preference of power supply system using a diesel-PV hybrid system over a local mini- or micro-grid for financial reasons. In some more remote areas, a combination of high petroleum fuel prices, difficult fuel delivery logistics and land availability for fuel crop farming, may favour introduction of plant oil or bio-diesel generating sets into the hybrid systems in place of the ordinary standard diesel generating sets. Following hereunder are a few examples:

5.1.1 Financing PV in Pre primary (preschool) education

The educational institutions at this stage are mainly privately organised. There is seldom any control or monitoring by the state, if at all. As a result, statistical data about preschool centers is currently not available. So, for the purpose of this thesis, financing of PV at day-care centers will only be discussed in principle, about what should be done and how. Due to lack of government support for preschool centers in Tanzania, financing of any aspect of educational activity at this stage, including any PV projects, will have to be privately financed through private arrangements between owners of these institutions and financiers and/or suppliers and installers of the required services. State involvement may come in, if at all only indirectly in form of its influence as a regulator and facilitator in other elements of the project, for example as regulator in financial and banking systems, general regulation of educational standards and health standards, land acquisition and ownership, or settlement and development control.

Educational institutions at this stage are mainly day-care centers with activities mainly during daytime. The main need for electricity at this level of educational institutions would comprise of powering **information systems** such as computers, their networking hardware and their peripherals, entertainment/edutainment gadgets for the children, as well as charging of cellphones for teaching and administrative staff.

Daylighting through appropriate design of education facilities should be more emphasised to alleviate need for daytime **electric lighting**. Night artificial lighting may be required in staff and children's residential quarters if they are included in a particular pre-school project. **Water pumping** may also be an important PV application at a day-care center especially in areas without centralised water supply systems. Another major energy need at these institutions would be for preparing meals for the kids but this need can be better catered for by more traditional systems, such as biomass (wood and charcoal), which with improved fuel saving stoves would constitute the most reasonable and environment friendly carbon-neutral solution. Alternatively cleaner burning gaseous fuels, preferably biogas with specialized specifically adapted cooking stoves would be more appropriate for many centers. (In logistically more accessible locations liquefied petroleum gas or natural gas LPG, LNG may be initially used).

Electricity demand calculations indicate that only 3 PV modules @40W_p or 50W_p plus 3 automotive lead acid batteries, charge controller and appropriate wiring are required but but any financing plan must also include the necessary ICT load, at least one laptop and its peripherals assuming the caretakers to already have their own cellphones. Such a small hardware package may cost between **€ 1000 - € 2000** up-front cash. In the absence of either well established equipment supply systems or reasonable credit facilities, as is currently the case in many situations in tropical developing countries, such an amount should be included in the centre financing project. (In developed countries such as Germany, by comparison, such a hardware package may be obtained for free in advance, or on a financial credit repayable over two years in addition to the communication costs according to available customer service packages, such as call & surf flat rates, or call by call packages.)

The major ownership pattern at this level is non-governmental institutions, mainly through private, religious, or other charity organisations. Therefore, the strategy for financing of PV in such institutions (including not only the energy requirements itself but also the gadgets that utilise the energy, with PV energy resources only as a necessary component to enable the gadgets to run) should focus on the financial capabilities of the institutions and their usual clientele, allowing for opportunities to repay the financial resources with a reasonable interest, and within reasonable time so that these resources can be used to finance similar projects elsewhere.

6.2.1. Financing PV in Primary Education

Primary education in Tanzania is almost entirely in state hands both by ownership and control. Most of the primary schools in Tanzania are ideal candidates for PV based electrification because they are located in rural areas without grid connection nor prospects for grid based electrification in the near future. Similar to day care centers, primary schools operate mainly during daytime with children coming from their homes. Therefore, their electricity demands should, ideally, be dominated by powering of ICT devices such as cellular phones, computers, their networks and their peripherals for teaching/learning and administrative activities to be used by staff and pupils. The intensity of use of such gadgets, however, is as expected to be higher than for preschool day care centres. Other uses such as water pumping, lighting and domestic refrigeration would be necessary in limited special cases and staff residential quarters.

For the general estimate of costs of PV installations in all primary schools in Tanzanian, it has been assumed that all primary schools are day-schools, and so do not require night lighting, PV is used only for powering ICT and only 45 laptop computers are used at each primary school. The current PV price index of 4.71 Euros/Watt has also been assumed. Using the latest available statistical data about school numbers and enrolment in Tanzania (for year 2007) with a breakdown according to administrative regions (rough equivalent to German Federal States or *Länder*) the financial requirements has been calculated as shown in table 6.3 below.

From this table it may be inferred that in order to run just 45 laptops per primary school in Tanzania, **70,3 MWp** of **PV** would be required, costing **€ 331.5 million** and **€351.5 million** for the associated **ICT equipment**. The total cost would be **€ 682.7 million**. This capital investment is presented in table 6.3 as a breakdown according to administrative regions that may help in implementing a phased project financing. In such a phased implementation, it is hereby recommended to take preferably **a few schools at a time in each region** rather than a few regions at a time

Financing of PV in the primary education system in Tanzania, should therefore, be viewed in terms of financing the provision of ICT, for educational and entertainment purposes and PV itself only as a means of powering this ICT.

PV may be considered for water pumping and electric lighting purposes in the primary education system in boarding schools for children with special needs and for staff residential quarters. Some boarding facilities may also be provided for private primary schools which, although now increasing, are still rare. Financing of PV powered water pumping in primary schools should go along similar arrangements as for pre-school institutions or alternative methods involving both the parents and the government may be devised. A third method could be a credit to the school as a special income generating project the cost would be recovered plus a reasonable margin for the school through sale of water to the neighbouring community. In such a case it is important to consider alternative water sources and their costs to the general neighbouring population, their income and their set of priorities that determine not only their ability but also their willingness to pay for the water supplied. In such a case the PV project may be used as a training ground for future workers for both the water supply and PV installation industry.

Table 6.3: Financial requirements for PV powering of ICT in primary schools in Tanzania.

Administrative Region of Tanzania	Number of schools	Total pupil Enrolment	Total power demand	Load equipment cost	PV Energy equipment cost	Total cost
		(Std I-VII)	(W)	(€)	(€)	(€)
Arusha	524	326414	2358000	11790000	11106180	22896180
Dar es Salaam	428	499590	1926000	9630000	9071460	18701460
Dodoma	894	454760	4023000	20115000	18948330	39063330
Iringa	871	384149	3919500	19597500	18460845	38058345
Kagera	1009	501041	4540500	22702500	21385755	44088255
Kigoma	615	362328	2767500	13837500	13034925	26872425
Kilimanjaro	902	347092	4059000	20295000	19117890	39412890
Lindi	446	176219	2007000	10035000	9452970	19487970
Manyara	518	275973	2331000	11655000	10979010	22634010
Mara	680	422354	3060000	15300000	14412600	29712600
Mbeya	1128	549374	5076000	25380000	23907960	49287960
Morogoro	1006	404575	4527000	22635000	21322170	43957170
Mtwara	597	243271	2686500	13432500	12653415	26085915
Mwanza	1157	812006	5206500	26032500	24522615	50555115
Pwani	502	217678	2259000	11295000	10639890	21934890
Rukwa	510	287526	2295000	11475000	10809450	22284450
Ruvuma	700	280763	3150000	15750000	14836500	30586500
Shinyanga	1096	694752	4932000	24660000	23229720	47889720
Singida	453	266780	2038500	10192500	9601335	19793835
Tabora	682	364503	3069000	15345000	14454990	29799990
Tanga	906	455777	4077000	20385000	19202670	39587670
Total	**15624**	**8326925**	**70308000**	**351540000**	**331150680**	**682690680**

6.2.2. Financing PV in Secondary Education

Secondary schools are expected to be the major candidates for PV electrification in the Tanzania educational system in the foreseeable future. This is a result of a combination of factors, the major ones being the level of education provided at Secondary level that encourages a more intensive use of modern ICT facilities and equipment such as computers and their peripherals and the current Tanzanian government policy of expansion of Secondary Education *(Mpango Maalum wa Elimu ya Sekondari -MMES)* which has promoted the construction of many Secondary Schools in all far flung areas across the country, mostly in rural and remote areas far away from grid services. Before introduction of this policy most secondary schools were be built near cities and towns with grid electricity. Despite their now increasing numbers, secondary schools are still not as widespread as primary schools and some pupils have to attend their schools so far away from their home that they are encouraged to look for alternative accommodation near their schools. Construction of students' hostels and other boarding facilities, either by the school authorities within school premises or by private entrepreneurs near targeted secondary educational facilities is currently under way.

Demand for electricity in secondary schools is much higher than that in primary schools partly because of the expected higher and longer use of ICT facilities and other electronic devices as well as a more clearly defined need for electric lighting in the boarding facilities. Electricity demand in staff residence quarters is also higher partly because of the higher living standard expected of secondary school staff with higher disposable incomes compared to their primary school colleagues, and partly as a means to attract and retain them in the newly opened secondary education institutions in remote areas.

Electricity demand pattern at a Secondary school center also varies over the 24 hour daily cycle, peaking during the evening hours from sunset to about 10 0clock at night, when most of the pupils and staff are busy with their evening preparations. Afterwards, many are supposed to go off to sleep and, therefore, most social and academic activities go into low gear. In remote secondary school centers far from the grid, this energy demand pattern is a clear candidate of a **hybrid system**, in which PV takes care of the main load during the day and a diesel generator kicks in for a short time after sunset to take care of the peak load and finally batteries (charged by the PV and diesel generator) take over for the rest of the night till sunrise. Such an arrangement saves money on the PV modules array which has to be dimensioned only for the daytime base load instead of the total maximum power demand. It also saves money on the battery storage system which has to be dimensioned to stabilize ICT power supply and provide low demand electricity for only a part of the night. It does not have to be over-dimensioned for the no-sun safety margin, as in ordinary stand-alone PV systems so as to provide the power security for given number of days without being recharged, as this will be covered by the diesel standby-generator. With the PV-diesel hybrid system, this overdimensioning and the associated increment in initial capital investment, of the storage system is avoided.

In areas with enough land for cultivation of both food and energy crops, fuel costs for the diesel generator may be further reduced by using fuel oil from locally grown energy plants e.g. *Jatropha curcas*. This is a measure of further reduction of total costs through reduction of running costs and security against petroleum based fuel costs. In addition, there are a number of associated environmental benefits (through improved carbon emission parameters) and social benefits mainly as a means of providing additional jobs, job security and associated incomes in rural communities around these Secondary schools, through Jatropha cultivation and fuel oil processing.

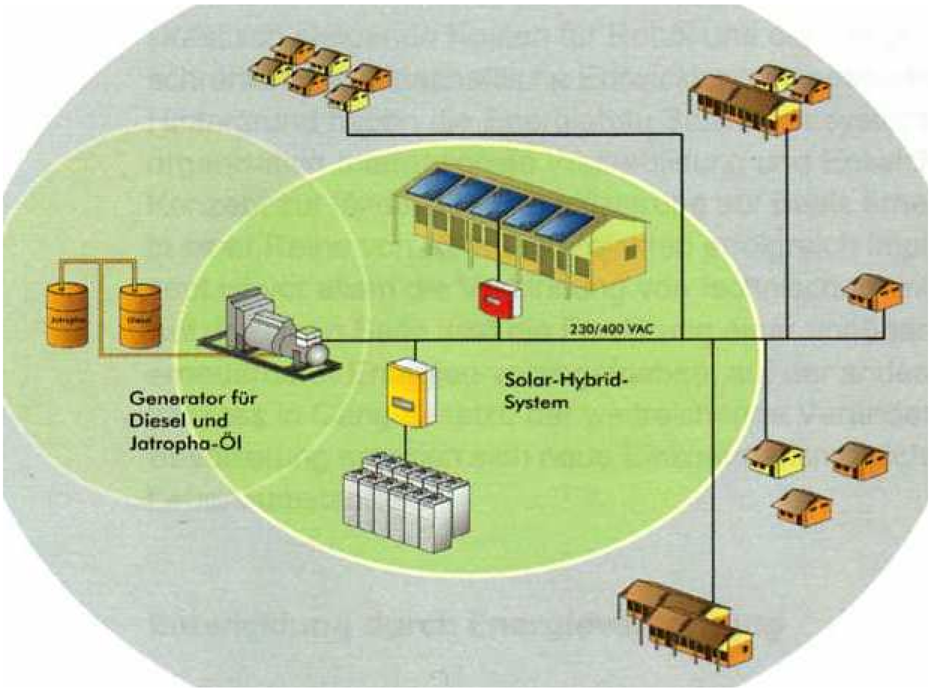

Fig. 6.1: Schematic representation of a PV-Biodiesel hybrid system supplying electricity to a small village (Vocational training center) over a local microgrid system *(Energiebau GmbH)*

In addition to modules and batteries, the power management of an autonomous PV power supply system, includes charge controllers and inverters but this contribute only minimally to the total system costs. A complete comparison chart that compares the costs alternatives for PV stand alone or hybrid solutions would follow the train of thought represented in table 6.4 below. However, due to their minimal contribution to overall investment cost and the current volatility of such costs, leading to difficulty in obtaining current and long term valid data, especially labour, the author considers it sufficient to consider the major initial capital layout only, namely, PV modules and batteries as well as diesel generating sets.

Table 6.4. Cost comparison for stand-alone PV and PV-Jatropha-oil hybrid

Option Number	Generation Option description	Upfront Capital cost items	Running cost items	Comments
Basic PV only options				
1.	PV alone. distributed	PV modules Batteries Charge controllers Inverters	Distilled water Labour	Very little labour for module cleaning and battery Maintenance
2.	PV alone. centralised	PV modules Batteries Charge controllers Inverters Minigrid	Distilled water Labour	Very little labour for module cleaning and battery maintenance
Basic PV-hybrid options				
3	**PV+Bio-diesel** PV for daytime requirements (ICT) + Bio-Diesel gen-set for early evening + Batteries the rest of the night	PV modules (few) Batteries (few) Charge controllers Inverters Diesel gen-set Minigrid	Fuel oil Lub-oil Filters Distilled water Labour	More labour for the above named tasks plus biodiesel farming and regular gen-set maintenance
4	**PV+Petro-diesel** PV for daytime requirements (ICT) + Petro-Diesel gen-set for early evening + Batteries the rest of the night	PV modules (few) Batteries (few) Charge controllers Inverters Diesel gen-set Minigrid	Fuel oil Lub –oil Filters Distilled water Labour	Same as above minus biodiesel farming
Other options				
5.	Petro-diesel + batteries	Diesel Gen-set Batteries Charge controllers Inverters Minigrid	Fuel oil Lub –oil Filters Distilled water Labour	Labour for battery and gen-set maintenance.
6.	Bio-diesel+ Batteries	Diesel Gen-set Batteries Charge controllers Inverters Minigrid	Fuel oil Lub–oil+ Filters Distilled water Labour	Labour for biodiesel farming, battery bank and gen-set maintenance
7	Petro-Diesel alone	Diesel Gen-set Minigrid	Fuel oil Lub-oil Filters Labour	Labour for gen set maintenance
8.	Bio-diesel alone	Diesel Gen-set Minigrid	Fuel oil, Lub-oil, Filters Labour	Labour for biodiesel farming and gen set maintenance

For purposes of investment and cost calculations it is important to compare comparable factors over a common project lifetime period. Different system elements have different life as observed in real life situations or based on manufacturers' data. However the most prudent project lifetime consideration is based on the guaranteed lifespan period for most PV modules which is 20 years. However, it is known that crystalline PV modules have a longer technical lifespan beyond the guarantee period. In real-life situations, most PV modules at 25 years of age are known to still give reasonable amounts of energy (i.e. within 80% of their initial rating). Some installations have been reported to last even 30 years and more. The currently emerging thin film technology is promising to reduce the initial capital. However due to the current short guaranteed life time of thin film PV modules, the Crystalline module is still the best option for long term PV investment. However, it is to be hoped that Thin Film technology holds great promise if and will therefore The 20 project lifetime capital investment costs of different items are as summarised in the following table hereunder:

Table 6.5: Project lifetime capital costs for different power system components

S.No	**System item**	**Expected item life (years)**	**No. of changes over project lifetime**	**Unit initial investment cost**	**Item unit cost over project lifetime**
1.	PV modules (Crystalline)	20	1	4.71 €/Wp	4.71 €/Wp
1 (b).	PV modules (Thin film)	10	2	2.36 €/Wp	4.72 €/Wp
2	Batteries	7	3	1.31 €/Wh	3.93 €/Wh
3	Diesel gen. set	10	2	0.381€/W	0.762 €/W

Using the latest information on pupils' enrolment and teaching staff availability from the Basic Educational Statistics for Tanzania (BEST) for 2007 an average Tanzanian Secondary School was calculated to have 273 pupils and 8 teaching staff members. From available information about current teaching programs in most secondary schools it was seen that the main electricity consumers in such a Secondary School were ICT (computers & related technology) for most of the day and mainly lighting for the night, and the highest lighting requirements are in the first 4 hours of the early evenings, approximately from 6:00 pm to about 10:00 pm (22:00 hours) Using this information the power requirements and total daily electric energy requirements and costs are calculated as seen in table 8.xcv below. The power of the required diesel generating set has been estimated taking into account a generator efficiency (cos phi) of 0.8.

Table 6.6: Energy requirements in a typical Tanzanian Secondary school

	Energy requirements		**Energy management resources and costs**					
Activity	**Total Power**	**Daily Energy requirement**	**PV modules requirement**		**Batteries (80% DoD)**		**Equivalent Diesel generator**	
	W (kW)	**Wh/d (kWh/d)**	**Wp (kWp)**	**Euro**	**Ah (kAh)**	**Euro**	**kW**	**Euro**
Lighting	11652.35 (11.7)	28344.30 (28.4)	5154 (51.5)	24275.34	2953	46421.16	14.57 =15.00	11430
ICT	3696 (3.7)	28302.50 (28.3)	5146 (51.5)	24237.66	2948	46342.56	4.62 =5.00	3810
TOTAL	15348.35 (15.3)	56646.8 (56.7)	10300 (103)	**48513.00**	5901	**92763.72**	19.18 =20.00	**15240**

From the above table, it can be seen that the PV-Jatropha hybrid system has lower capital investment costs compared to PV alone. This is from the inference that if the whole secondary school were to be run on PV alone, then the necessary up-front capital layout would be as follows: PV modules, (€ 48,513.00) + Batteries

Table 6.7: Cost comparison between PV-stand-alone and PV-Jatropha Oil hybrid for powering Secondary School.(based on the current programs in Tanzania)

Options	**PV Modules**	**Batteries**	**Gen set**	**Power Management (Inverters/ charge controllers)**	**Total capital invest.**	**Remarks**
PV stand-alone option for the whole Sec. School	48513.00	**185526.44** (= 2 x 92763.72)		Charge control 4796.36 + Inverter 7090.94 =**11887.30**	**245926.74**	Battery storage has to be doubled for power security
PV-hybrid with Diesel Genset running on Jatropha oil	24237.66	46342.56	15240	Charge control 1155 + inverter 1707.55 =**2862.55**	**88682.77**	Battery capacity has to pack is just for PV system stability

From the foregoing analysis we see that capital investments are lower in a PV-jatropha oil hybrid than in PV stand alone solution. With the same total load, PV modules are fewer, calculated to take care of only the daytime portion of the load, mainly ICT, the generator set takes the evening peak, while batteries which are only a quarter of the stand alone capacity, take over the rest of the night and assure stability against solar radiation fluctuations during the day. The main running costs emanate from daily fuel consumption and maintenance service of the generator. However, with fuel being locally produced from locally grown Jatropha plants, the whole picture looks more attractive than purely stand-alone PV.

A cost analysis was conducted and it was found that at the current (2008) level of prices and school numbers, it is possible to electrify all Secondary Schools in Tanzania, using the **PV-Jatropha Oil hybrid system** at a cost slightly more than **323 million Euro**, in capital investment for purchase of PV modules, batteries, power management equipment (charge controllers and inverters) as well as diesel engine generator sets modified to run on Jatropha Oil. A regional-by-region breakdown is presented in table 6.8. Location of the secondary schools is an important criterion for funding of PV electrification. In some regions such as Dar es Salaam and Kilimanjaro where land is scarce and conventional grid electricity is already available, the best electrification option is just simple grid connection. In remote rural areas far away from the grid the above cited example of PV in hybrid with Jatropha oil is indeed the best electrification option. Some regions, eg Rukwa require as low as Euro 6.7 million. In these least technologically developed areas with low population densities and ample agricultural land where Jatropha could be easily grown and maintained through harnessing local labour, this is indeed a good option to seriously consider.

The ownership pattern of Secondary schools in Tanzania is highly mixed. Some Secondary schools are traditionally owned by the government, some are owned by religious organisations, others by community organisations partly helped by the government and others by private organisations and individuals on commercial basis. Financing of PV in secondary schools will have to take into account all these different factors such as forms of ownership and location of individual schools, availability of agricultural factors for growth of Jatropha plants as well as the varying financial capabilities and the generally higher energy demands in secondary schools as compared to primary and pre-primary institutions.

Table 6.8: Breakdown of Capital layout in Euros for electrification of Tanzanian Secondary schools using PV-Jatropha oil hybrid system.

Region	Number of Sec. Schools	Cap. Invest. for PV modules [€]	Cap. Invest. for Batteries [€]	Cap. Invest. For Power Mgt. Eqpt [€].	Cap. Invest. for PV total [€]	Cap. Invest. for Diesel. Genset [€]	Total Capital Invest [€]
Arusha	149	3611411.34	6905041.44	426519.95	10942972.70	2270760	13213732.7
DaresSalaam	241	5841276.06	11168556.96	689874.55	17699707.6	3672840	21372547.60
Dodoma	173	4193115.18	8017262.88	495221.15	12705599.2	2636520	15342119.20
Iringa	193	4677868.38	8944114.08	552472.15	14174454.6	2941320	17115774.60
Kagera	184	4459729.44	8527031.04	526709.20	13513469.7	2804160	16317629.70
Kigoma	102	2472241.32	4726941.12	291980.10	7491162.54	1554480	9045642.54
Kilimanjaro	293	7101634.38	13578370.08	838727.15	21518731.6	4465320	25984051.60
Lindi	89	2157151.74	4124487.84	254766.95	6536406.53	1356360	7892766.53
Manyara	85	2060201.10	3939117.60	243316.75	6242635.45	1295400	7538035.45
Mara	152	3684124.32	7044069.12	435107.60	11163301	2316480	13479781.00
Mbeya	245	5938226.70	11353927.20	701324.75	17993478.7	3733800	21727278.70
Morogoro	174	4217352.84	8063605.44	498083.70	12779042	2651760	15430802.00
Mtwara	124	3005469.84	5746477.44	354956.20	9106903.48	1889760	10996663.50
Mwanza	253	6132127.98	11724667.68	724225.15	18581020.8	3855720	22436740.80
Pwani	172	4168877.52	7970920.32	492358.60	12632156.4	2621280	15253436.40
Rukwa	76	1842062.16	3522034.56	217553.80	5581650.52	1158240	6739890.52
Ruvuma	138	3344797.08	6395273.28	395031.90	10135102.3	2103120	12238222.30
Shinyanga	265	6422979.90	12280778.4	758575.75	19462334.1	4038600	23500934.10
Singida	114	2763093.24	5283051.84	326330.70	8372475.78	1737360	10109835.80
Tabora	129	3126658.14	5978190.24	369268.95	9474117.33	1965960	11440077.30
Tanga	294	7125872.04	13624712.64	841589.70	21592174.4	4480560	26072734.40
TOTAL	**3645**	**88346270.7**	**168918631.2**	**10433994.8**	**267698897**	**55549800**	**323248697**

6.2.3. Some questions relating to the Jatropha economy

In Jatropha and any other energy crops' cultivation schemes, there are a number of other issues, pertaining to agricultural land management and food security, that need to be addressed. In the interest of better agricultural land management, monoculture, in form of specialised large scale Jatropha plantations must be avoided. The question of biofuel cultivation for export purposes taking over land and labour for local food production must also be carefully addressed. An adverse link between increase in biofuels cultivation and the rise in food prices is currently under discussion. The World Bank claims that the biofuels boom is responsible for 75% of the increase in global food prices since 2006 *(DFID 2008)***.** In this particular case, however, the Jatropha plant may be grown as a living hedge around small-holder farmers' plots or by intercropping with other traditionally grown food or "cash" crops in specialized small-holder farmstead sections rather than large commercial plantations. In addition, all the products of the Jatropha industry can (must) be locally utilised. The oil can be used not only for the generator but to power other diesel-engined machines such as tractors and transport vehicles, thereby saving money on the expensive petroleum diesel and saving the environment through reduced carbon emission. The press-cake residue from Jatropha oil processing can be used to generate biogas for cooking and running gas-engine vehicles and other machines. Finally the residue after biogas generation may be used as soil fertiliser. The fact that Jatropha itself or its oil is not food and the plant cannot be eaten by animals is an important argument in its favour and against it. When planted as a living hedge around food-crop plantations, then in addition to fuel production and other advantages cited above, Jatropha also helps protect food plantations or smallholder farms against being eaten by animals and other food pests. In large monoculture export-oriented plantations, however, the fact that Jatropha is inedible presents the strongest argument against it in that such plantations take land and labour resources away from food production.

6.3. Financing of PV in rural health care

Most basic healthcare facilities (dispensaries) in Tanzania are owned by the Government through local (district) governments. These dispensaries are mostly situated in rural areas without electricity. Because of their sizes and scope of activities, functioning mainly by day and carrying out no major surgical operations, these dispensaries are candidates for stand-alone PV.

The second higher level, bedded dispensaries and health centers, are also situated in rural areas but because of the scope of their activities, they need 24 hours electricity supply which, if not supplied through the mains grid, then a local diesel powered minigrid is usually installed. These ones could benefit from a PV-Biodiesel hybrid with the biodiesel part running on Jatropha oil, just as it has been demonstrated above for secondary schools. The power of the Bio-diesel generator should be calculated to take care of the maximum load, but the battery only reduced to the minimum capacity to power the base load, with no reserve capacity. In case of an envisaged higher power demand (or higher power security demand, e.g. during a surgical operation) the bio-diesel generator may be manually started. It may also be made to automatically switch-on when the battery state of charge reaches a preset critical minimum. This saves on battery capacity over-dimensioning as an energy security margin. The exact financial requirements may be decided on a case by case basis depending on the size and complexity of the health facility.

6.4. Financing of rural public administration

As for public administration in rural areas, all public offices below district level do not have power supply and therefore, no electronic public administration information systems (PAIS) which is necessary for their effective and efficient function. At the lowest government administrative level, the Village Executive Officer *(Ofisa Mtendaji wa Kijiji)* does not even have a specialised working place but works from his own house or some rented premises. Above this officer, there ere are two main administrative levels, the Ward Executive Officer *(Ofisa Mtendaji wa Kata)* and the Division Executive Officer*(Ofisa Mtendaji wa Tarafa)* which come just before the District Executive Offisicer *(Ofisa Mtendaji wa Wilaya)*. These two officer above village level usually sit in some kind of official working place, often co-located with rural justice delivery offices i.e. primary courts, but often without any electronic information systems, neither for Public Administration (PAIS) nor for Justice Administration (JAIS). They usually use handwritten paper based documents and at best may have a manual typewriter. It is at these lower levels where PAIS's, and PV to power them, are required. District Offices *(Ofisi za Wilaya)* are usually located in towns which are usually electrified from local public grid or connected to the main National Grid System. Electricity problems at District level are mainly associated the security of supply rather than actual presence of power supply.

The financing of PV for Public Administration in lower rural instances must, therefore, be considered in terms of provision of complete Public Administration Systems, beginning with specialised **office buildings** equipped with the necessary **hardware and software** for public administration information systems (PAIS) all powered by a matching PV system. (For facilitation of system administration, a completely integrated PV powered e-Government system incorporating PAIS, JAIS, e-Police and e-Health facilities, may be installed at each village, and integrated through an appropriate communication network protocol, (LAN, WAN, GSM, GPRS, UMTS, Mesh Networks etc.) all the way up to district and national levels, in which different officers may have access limited to their own areas of activities. Training of the officers and system administrators in both PV and ICT should also form part of the package).

The costs for these installations are as presented in table 6.9 (a, b, c)

Table 6.9(a): PV & ICT hardware costs calculations for local government administration offices

	PV module cost (crystalline)	PV module cost (thin film)	Battery cost	ICT equipment cost	PV system cost (w/cryst. Mod.)	PV system cost (with thin film mod.)	PV+ICT system cost (with cryst. mod.)	PV +ICT system cost (with thin film mod.)
	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]
Vijiji	5196825,60	2603929,60	542025,60	10344000,00	5738851,20	3145955,20	16082851,20	13489955,20
Mitaa	881712,00	441792,00	91962,00	1755000,00	973674,00	533754,00	2728674,00	2288754,00
Kata	1604540,00	803973,33	167352,50	2555000,00	1771892,50	971325,83	4326892,50	3526325,83
Tarafa	388857,60	194841,60	40557,60	516000,00	429415,20	235399,20	945415,20	751399,20
TOTAL	8071935,20	4044536,53	841897,70	15170000,00	8913832,90	4886434,23	24083832,90	20056434,23
TOTAL CHK	8071935,20	4044536,53	841897,70	15170000,00	8913832,90	4886434,23	24083832,90	20056434,23

Table 6.9 (b): PV & Home appliances hardware costs calculations for local government administration staff housing

	PV cost (crystalline)	PV cost (thin film)	Battery cost	Home appliances costs	PV system cost (w/cryst. Mod.)	PV system cost (with thin film mod.)	PV (cr) sys+Home Appl. cost	PV (thn-flm) syst+Home Appl.cost
	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]
Vijiji	7881852,16	3949293,23	822072,16	3103200,00	8703924,32	4771365,39	11807124,32	7874565,39
Mitaa	1337263,20	670051,20	139475,70	526500,00	1476738,90	809526,90	2003238,90	1336026,90
Kata	1946841,87	975487,64	203054,37	766500,00	2149896,23	1178542,01	2916396,23	1945042,01
Tarafa	393178,24	197006,51	41008,24	154800,00	434186,48	238014,75	588986,48	392814,75
TOTAL	11559135,47	5791838,58	1205610,47	4551000,00	12764745,93	6997449,04	17315745,93	11548449,04
TOTAL CHK	11559135,47	5791838,58	1205610,47	4551000,00	12764745,93	6997449,04	17315745,93	11548449,04

Table 6.9 (c) Totals for ICT & housing costs

Total for ICT+Housing	**19631070,67**	**9836375,11**	**2047508,17**	**19721000,00**	**21678578,83**	**11883883,28**	**41399578,83**	**31604883,28**

6.5. Motivations for funding institutional PV projects in developing countries

PV projects, with their usually large upfront capital layouts, are generally expensive. Concern for the environment alone would not be enough to motivate most implementers to use the solar option. Therefore, another good motivation for funding of PV project must be found and put forward before finance can be obtained. In most cases this could be the stated as a need for the particular service with PV as the most appropriate means of powering the provision of that service. A commercial or entrepreneurial justification of the investment would motivate most financial sources. A governmental leaver in form of a law, regulation or enforceable implementation standard can force some service providers to comply. Economic leaver in such as special subsidies and similar incentives may be employed. In developed countries these incentives are made in form of various subventions, grid feed-in tariffs and other legal and financial instruments. In Third World countries, such an approaches haven't yet been tried partly because of politicians' and law-makers' ignorance, limited state funds in face of other state priorities, low purchasing power of the target population groups and missing grid coverage. Another motivational option is **"Creative capitalism"** which according to *Bill Gates (2008)***,** is a philanthropic approach by big corporations, which has subsequently been modified by *Martin Wolf (2008).*

6.6. PV project financing strategies

Introduction and application of PV in education, healthcare and public administration can be implemented following a number of action plans which may be commercial or not:

6.6.1. The non-commercial model in PV project financing

Non commercial implementation strategies include project implemented:

- As purely government grant funded projects (without cost recovery intentions). Such projects can be financed by the government as research project, industrial promotion projects or just energy demonstration projects.
- As government loan funded projects (with an element of cost recovery). In this particular case the money may be refunded by user payments through a specialized scheme. The government merely provides the resources to surmount the so called "initial investment barrier".
- As purely private funded projects (on philanthropic grounds, without cost sharing nor recovery motives). This can be implemented by a private welfare institution or by an individual with enough resources and good intentions.

6.6.2. The partly commercial model in PV project financing

A PV project may be funded by a combination of government grant and private investment in a **Public Private Partnership (PPP).** In this case it may have a reduced cost recovery element for only that part that is privately funded. The private part of the cost may be met by the users as payment for the services rendered though the PV project. For example, if a PV powered telephone service or internet café is partly funded by the state and private investor then the users may repay the private part through reduced telephone bills or internet use rates compared to what they would have paid had the service been fully privately financed.

6.6.3. The commercial model in PV project financing

The commercial mode, i.e. when implemented as purely private funded commercial projects (always with cost recovery +profit) is interesting because it is most likely to interest **private commercial finance** organisations but only if the possibility of realising a profit can be seen. PV may be supported as an independent part of a bigger construction project e.g. village or urban development schemes in which solar powered public service buildings such as schools, dispensaries or local government administrative centers would form a part. The solar and especially PV component would be relatively small compared to the overall project finance required, but its impact in terms of advantages derived from the services obtained or simplified would be great. In this case PV is selected from several electricity supply options, where economic calculations may help to justify the choice. The position of PV in this capacity would be further strengthened by such factors as:

- Remoteness of the project location from an existing electric supply grid.
- Bad or inexistence of road networks contributing to bad transport logistics for regular supply of fuel and spare parts for conventional fossil fuel based generation.
- The rising fuel prices further complicating the case for the fossil fuel alternative is a big incentive favouring the alternative energy systems including PV.
- Other deliberate incentives such as carbon taxes on convention electricity, tradable carbon credits for the projects, etc.

In all these cases, whether commercial, partly commercial or non-commercial, the need for "economic efficiency" (doing more with less resource) is always present. Therefore in implementing all these projects a "value for money" consideration must always be made. The best parts and processes in the then prevailing and expected immediate future circumstances, whether (political, social and economic) must be selected and clearly stated.

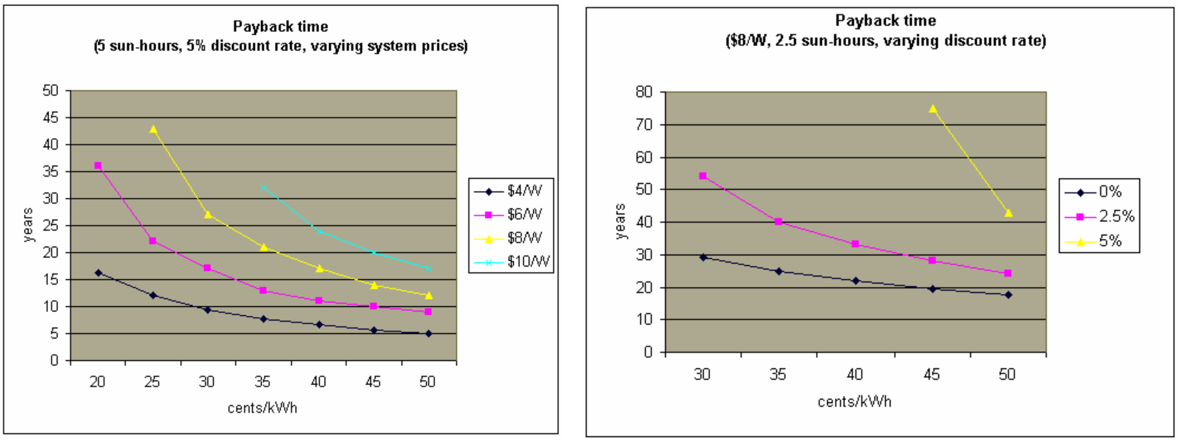

Fig. 6.2: PV project economic evaluations through payback period considerations

In finacing such projects, especially in developing countries, governance quality must be high. No corrupt practices should be tolerated at all especially by those in power. Unfortunately, cases have been noted lack of government control over financial institutions, (through ignorance or vested interests by high ranking government officials and/or their families, connivance of political and business figures) is a weakness that threatens to discourage interest of financial institutions investing in the PV sector at reasonable rates, by offering them alternative "highly profitable" albeit temporary and risky opportunities through corrupt and unethical practices. An infamous example is the case of **Bayport Financial Services**, where a private financial institution (partly?) owned by a close relative of an important political figure in Tanzania, to lured school teachers into taking credits charging 350% interest *Mbwambo (2008)* [[55]] exploiting their poverty, desperate need for cash and ignorance about the institution's policies. Some concerned individuals and organisations such as Transparency International (TI) are fighting hard against such practices. *Transparency International (2008)*

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[55] http://www.raiamwema.co.tz/08/07/23/mbwambo.php

6.7. PV project implementation strategies

There are several mechanisms of implementing PV projects either alone as self standing projects, as additions on existing buildings or as integral part of new building project.

The implementation strategies are selected depending on project size based mainly on the requirements at the project implementation area and available resources, which are themselves a result of the selected financing strategy.

- The project itself can be a relatively small one concentrated on one or several buildings all at one location (usually as a demonstration, a small commercial project, or a special project to satisfy local specific needs).
- Medium sized projects may include several PV installations over a larger area, say one or several an administrative districts or regions.
- Large scale implementation plans are usually nationwide.

Both medium and large scale projects are better candidates for partly and completely commercial financing because of the relatively larger potential profits even at low interest rates coupled to the relatively smaller share of per unit administrative costs or debt recovery measures in case of defaults. Depending on the financial rules, they are usually implemented in phases which may be distributed only geographically e.g. at least one school, dispensary or health center in each district, or region of the project zone (for medium sized projects) or of the nation (for large scale projects). A time phased and geographically distributed project implementation schedule may be instituted and sub-divided by objects e.g. at least one PV powered school in each district or region or only PV powered computer labs at all secondary schools in the whole nation.

There would be completely commercial financing if PV were already profitable at a large scale. However, so far the best way of financing PV is public investment by the state alone or in partnership with private capital. Many different financing mechanisms can be implemented by such agencies as the World Bank, The German Bank for Reconstruction (KfW) etc. Different programs such as the Carbon trading and the “Clean Development Mechanism” (CDM) are already in progress. In developed countries states have also used their power to institute legal measures such as emission limitation laws, carbon taxes, or economic incentives such as feed-in tariff. In the Third World however, some of these measures cannot be directly transposed partly because of the missing industrial and economic infrastructure. One cannot effectively speak about feed-in tariff when most of the potential energy users are not grid connected, and the grid itself is not yet reliable even for the few connected users. For example one cannot speak about effective carbon emissions reductions in production when actually all the production is still based on primitive human or animal power, or when biomass is the main source of energy for heat production is still biomass based. In such areas environmental management concepts of “deforestation control” and “land management” are more appropriate. However, these ones have limited direct bearing to PV applications except in the case of PV-Biodiesel hybrid systems are concerned.

Summary of Chapter 7: This is the final chapter of the thesis. It summarises the whole work and its findings. It is also closing with a set of conclusions and recommendations.

7. CONCLUSION and RECOMMENDATIONS

7.1. Summary of the work

Energy and electricity in particular, is a key element in development of any community, society or nation. Access to and use of electric energy is the most important single factor that determines the pace of development of a country and its people. In third world countries, most of which are tropical, this vital resource for development is still missing and the prospects are that if we continue with the "business as usual" ways of thinking and operation, the term "Developing Countries" will actually be meaning the opposite of itself. This work was conducted in order demonstrate a new way of thinking and acting, so as to enable Governments of technologically underdeveloped countries, most of which are tropical, to discharge their duties to their people, using the most traditional of all energy resources that is very abundant in their region, the sun, to power modern technologies including the most modern family of technologies, Information and Communication Technologies (ICT) by which our age has now come to be known.

The accomplishment of this work has been achieved through a number of methods that included:

- Information collection about the state of the art by examination of documents in various libraries and via the Internet.
- Examination and analysis of available related statistical data, for Tanzania and other countries.
- Field studies of some cases in Tanzania and abroad involving PV in rendering services similar to the intended ones for broader application.
- Site visits and attendance of exhibitions and conferences has proved to be a valuable source of both academic and industrial information that has been utilised in this thesis. Meetings with PV components manufacturers, systems dealers and integrators, for example, gave information about latest developments in the technology and its applications.
- Selection of a single Tropical Developing Country, Tanzania, use as a typical example and review of its Government set up, to establish the role of PV in facilitating the daily activities of each government ministry and the duty of each particular government ministry to enhance greater utilisation of PV

- Calculation of energy demand in a few sample typical service facilities (e.g. school, hospital and public administration buildings) and redesign of the same incorporating PV under tropical conditions.
- Actual design or improvement of existing standard design in view of incorporation of PV under tropical conditions.

7.2. Findings and Recommendations

The main finding of this research is that photovoltaics (PV) as a source of power is a highly suitable strategy in order to improve the performance of public institutions in providing their services including healthcare, education, public administration, police work and justice delivery.

In details these findings could be shown as follows:

a) Chapter 3 presented an analysis of power needs and the potential of use of the photovoltaics technology in the most significant government ministries in Tanzania. This analysis shows qualitative and quantitative demand for electricity as effective base for application of Information & Communication Technology (ICT) besides the building services. The ministries, therefore, have a role to play in enhancing wider use of PV technology.

b) This demand for ICT and hence for electricity is widely distributed at national level rather than centralized, and this demand is more acute below district level, especially in rural areas outside district headquarters where grid power is not available.

c) Therefore, distributed power generation as a decentralized option for generating power proved to be the most appropriate solution. In this respect, photovoltaics in form of stand-alone and hybrid installations is ideal to satisfy this demand in a short time without waiting for construction of a nationwide power grid system.

d) It is possible to implement this appropriate scheme in separate units both small and large (piecemeal realisation). Chapter 4 shows through a number of case studies in education, healthcare and public administration some estimates of the electricity needs and photovoltaics requirements. For example, the 15624 primary schools in Tanzania by 2007 would require 70.3 MW of stand-alone PV equipment costing € 331.5 million and €351.5 million for the associated ICT equipment. The total capital investment cost in this respect would be € 682.7 million. For secondary schools, especially those in remote rural areas, PV–biodiesel hybrid systems proved most appropriate. Here normal diesel generators modified to run on Jatropha oil are used. Capital investment requirement for them was € 267.7 million for PV systems coupled with €55.5 million worth of diesel generators, the whole investment totalling € 323 million. The exact figures for both primary and secondary schools are presented in breakdown according to administrative regions and it is proposed that in the absence of funds to implement a countrywide school electrification project then a phased implementation strategy can be adopted starting with a few schools in each region rather than a single or a few regions at a time.

e) The structure of government service is a hierarchical nationwide organised chain of command, and this is a great advantage in implementing successfully this new technology because of the inherent discipline and control mechanism that enables accountability. On the other hand, however, as state monopoly of power generation and distribution dies out in line with worldwide deregulation of the power sector, a form of Public Private Partnership (PPP) seems to be necessary in order to create good environment for private sector participation in the power supply systems, especially with small and medium scale distributed power generation, conditions in which PV stand-alone and hybrid systems operate in Tropical Developing Countries. For confidence building, a measure of state intervention in PPP with financial involvement and regulation of both technical and financial aspects of power supply and distribution is necessary

f) Chapter 5 develops and specifies building integrated photovoltaics (BIPV) for the special case of the tropics. The tropical solar path with seasonal declinations in both North and South orientation and intense solar radiation module necessitate quasi-horizontal installation of PV modules in order to achieve an optimal efficiency and the best annual solar harvest. Intense ventilation of BIPV modules is also critical to avoid overheating and subsequent efficiency reduction. Alternatively, less heat sensitive thin film PV modules are to be preferred to crystalline modules and therefore encouraged. Local assembly of BIPV roof elements before installation, e.g. lamination of flexible PV material on substrates, is to be encouraged in the interest of cost reduction and manpower training. The low availability of mechanized installation necessitates PV system design in small components to facilitate manual hoisting and installation. These detailed technical studies enabled realistic assumptions for PV energy yield and investments.

g) Financing models are available for implementation of small and large unit PV powered public service projects. Chapter 6 investigated various financing strategies for exemplary projects, including investment costs and estimable payback periods. It has been found that the best approach to financing PV electrification is that the choice between stand-alone and hybrid PV alternatives is be based on power requirement and power demand pattern, with a constant low daytime power demand favouring stand-alone PV while occasional short high power demands above a low base load, favour the PV-biodiesel hybrid alternative. In the power system both the PV modules and Balance of system (BOS) subcomponents such as wiring, charge controllers, batteries, inverters and loads should be carefully selected and matched for an overall optimal performance, both energy-wise and in economic/financial terms.

h) Of particular importance it has been shown that the best candidate PV is the local government administration setup below district level, namely the villages *(vijiji),* urban settlements *(mitaa)* wards *(kata, shehiya),* and divisions *(tarafa).* Although their power demand for administrative use of ICT and staff residential quarters is low, the effect of availability of PV powered ICT at this level will speed up the administrative communication network both horizontally and vertically through the government hierarchy, thus making the effectiveness of the presence of the government to be felt even in the remotest corners of the country.

7.3. Outlook

This study is fundamental for implementation of sustainable energy supply for powering government services in tropical developing countries. It has shown that sunshine, (solar energy), which is an abundant resource in these countries can be utilised to generate the necessary electricity to run many government services (both public and state services) which are now facing problems in delivery because of lack of energy.

This study has also opened doors for further research and other activities related to solar energy applications, such as the following:

- Demonstration projects for public buildings on local level. Monitoring, analysis, assessment, recommendations for future implementation
- More detailed programs for implementation of specific public services projects (e.g. education, health, public administration, policing and justice administration) at district or national level.

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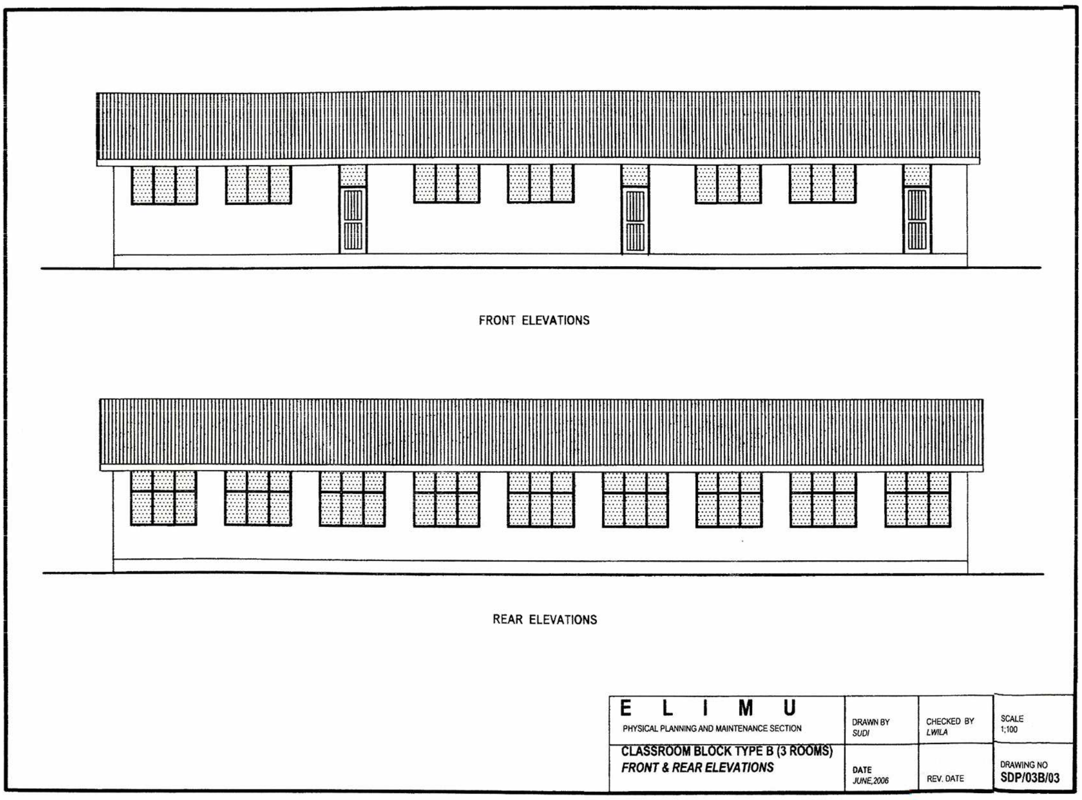
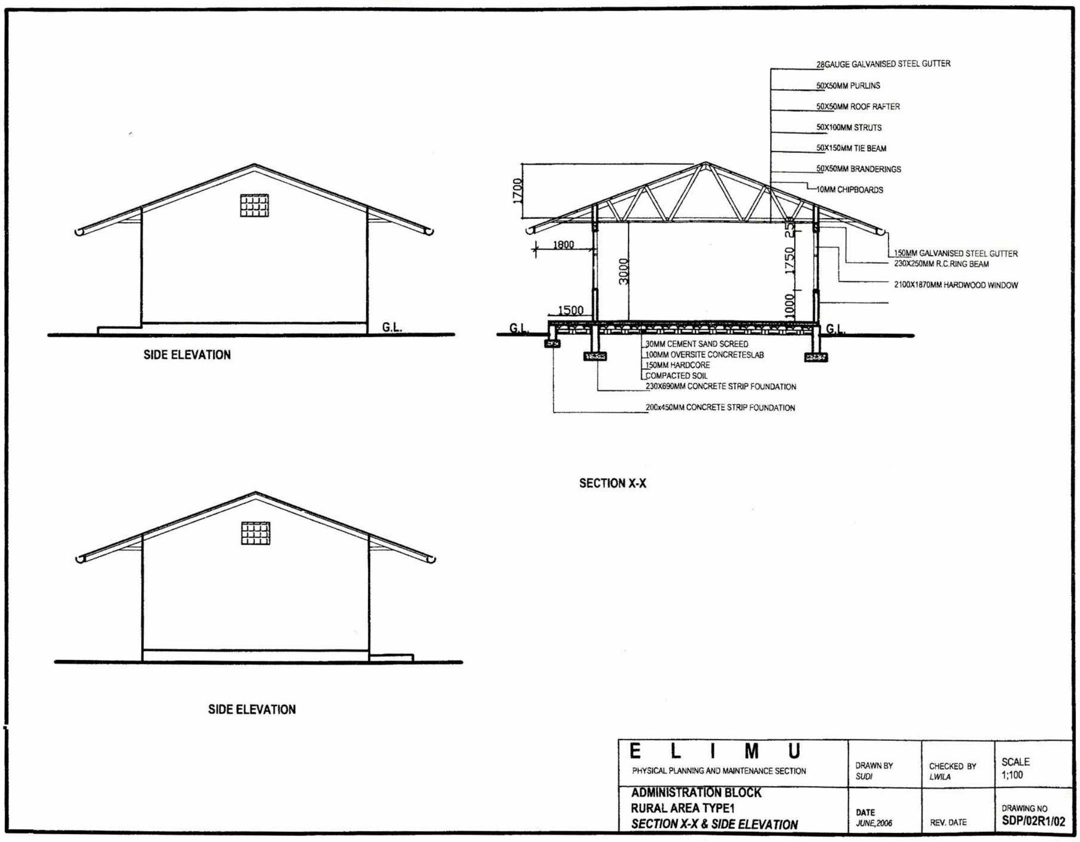
8.1. List of Table captions

8.2. List of Figure Captions

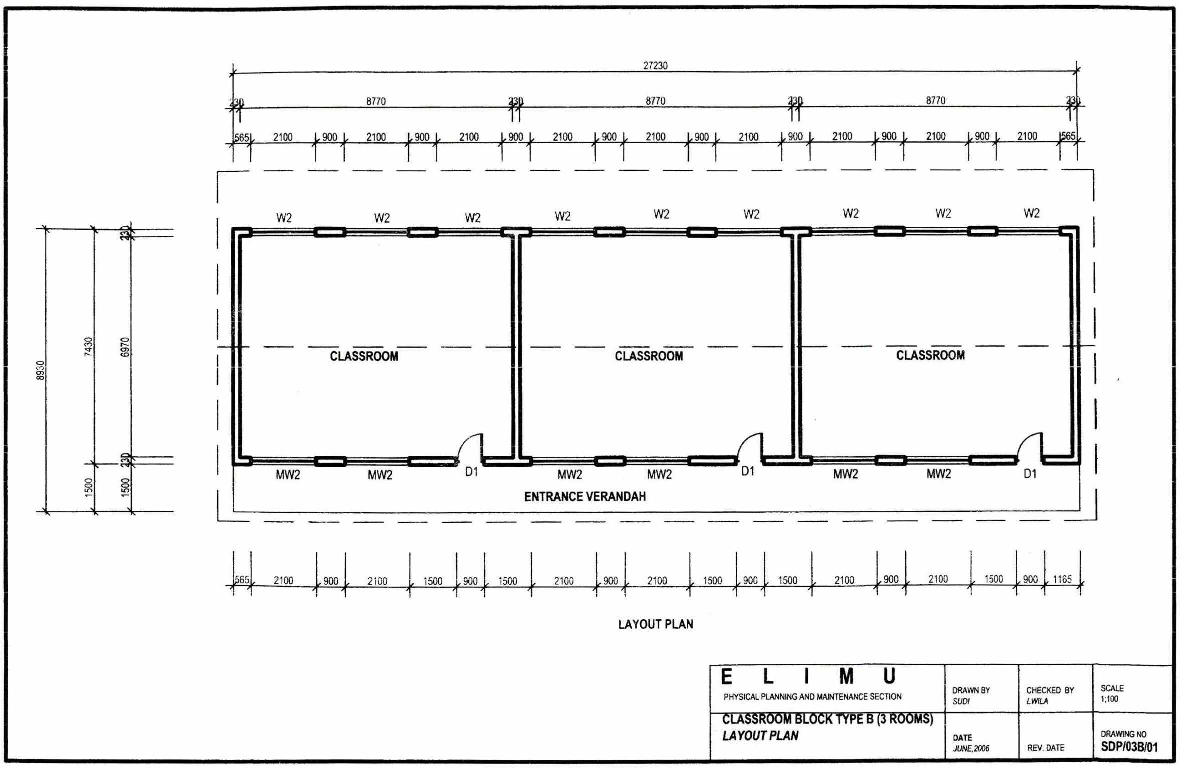
8.3. Annex 1: DRAWINGS OF STANDARD SCHOOL BUILDINGS FROM TANZANIA

(APPROVED BY THE MINISTRY OF EDUCATION AND VOCATIONAL TRAINING)

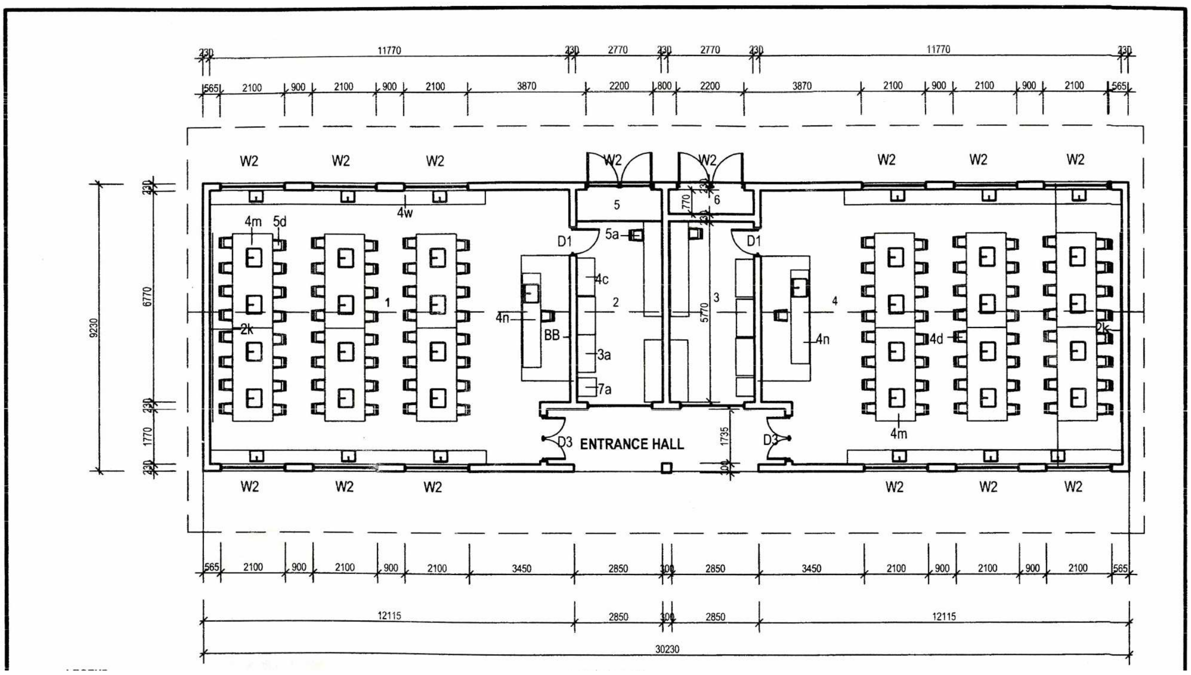




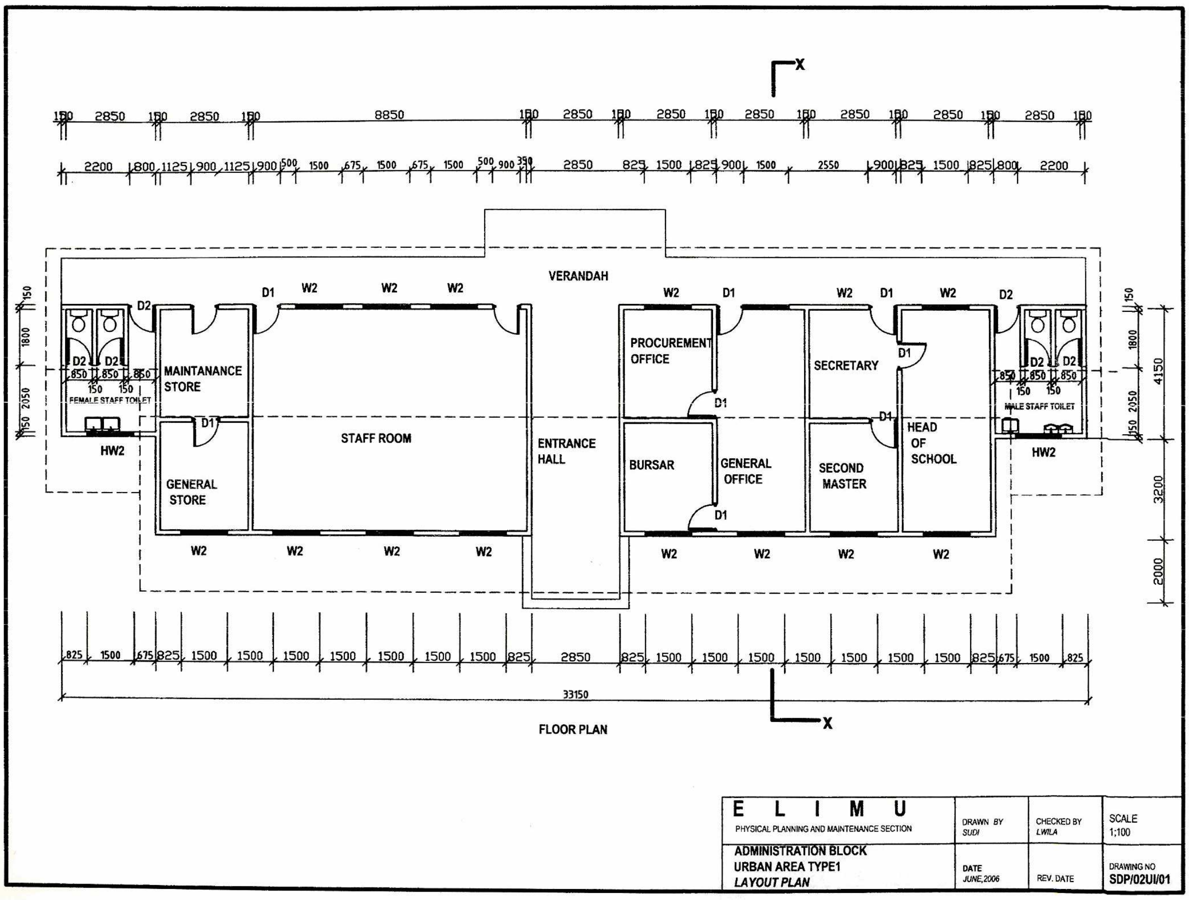
General façade elevations and section of buildings of standard school buildings. (floor plans may differ according to building function).



Floor plan of a typical classroom block



Typical floor plan of a laboratory block



Floor plan of a typical Secondary School Administration block

8.4. Annex 2: A CALL FOR A "MARSHALL PLAN" FOR AFRICA'S ICT DEVELOPMENT

While investment in ICT infrastructure in Africa has improved dramatically in recent years, representing a total of USD 8 billion in 2005 (up from USD 3.5 billion in 2000), and growth in mobile phones has increased by as much as 400 per cent, Africa has fallen back in overall connectivity. While mobile has surpassed fixed line telephone access, fewer than 4 out of every 100 Africans have Internet access; broadband penetration remains below 1 per cent; and 70 per cent of all Internet traffic within Africa is re-routed outside the continent, driving up costs for businesses and consumers.

"We need a Marshall Plan for ICT infrastructure development in Africa," said Dr Touré. "We have to mobilize the world's human, financial and technical resources to support economic growth, employment and development across Africa." He added that support was pouring in from partners in this endeavour, including from leading ICT companies in Silicon Valley and elsewhere — who have been given the challenge of replicating their successes in Africa — as well as from governments, international organizations and development banks. He pointed out that the Chairman of Intel Corporation Mr Craig Barrett is spearheading the efforts through his leadership of UN GAID.

With less than 8 years left to meet the 2015 targets of the UN Millennium Development Goals (MDG), drastic steps are required. Dr Touré pointed out that meeting ICT connectivity targets would act as a catalyst in achieving the broader development goals. "ICT is a means of creating wealth and sustainable economic growth," he said.

Source: ITU, (2007) http://www.itu.int/newsroom/press_releases/2007/18.html

8.5. Annex 3: Energy demand for a single dispensary taking Kishanje dispensary as a typical example

Medical units & space type	**specif. area reqmt.**	**quantity: people or items**	**Total Floor area.**	**specif. power reqmt.**	**Unit Power demand**	**daily use duration**	**Daily Energy reqmt**
	m^2 per person or item	p	m^2	W/m^2 (lighting)	W	h/d	Wh/d
One Unit: Kishanje Dispensary							
Lighting energy calc.							
Patients care buildings							
Main disp. Bldg		1	60	5	300	4	1200
Main wards building		1	100	2	200	6	1200
Matern. Labour ward		1	20	10	200	8	1600
Matern. Nurses office		1	12	5	60	10	600
Neonatal ward		1	20	5	100	8	800
Patients' Kitchen		1	12	5	60	4	240
Patients Toilets		1	4	2	8	2	16
Patients' washrooms		1	4	2	8	2	16
Subtotal1(Patientscare)		**8**	**232**		**936**		**5672**
Dispens. staff housing							
Sitting rooms	16	2	32	5	160	4	640
Bedrooms	12	4	48	5	240	1	240
Kitchens	3	2	6	5	30	4	120
Washrooms	2	2	4	2	8	1	8
Toilet	2	2	4	2	8	1	8
Subtotal2 (staff housing)		**12**	**94**		**446**		**1016**
Other Equipment **							
Medical Refrigerator		1					1900
Light Microscope		1			100	6	600
Cellphone		2					5
Radio (in staff residence)		2			50	4	200
TV (in staff residence)		2			3	5	15
Subtotal3 (electr.gadgets)							**2720**
Grand total (whole disp.)		**20**	**326**		**1382**		**9408**
Dispensaries in Tanzania		**2450**	**798700**		**3385900**		**23049600**

8.6. Annex 4: Local government energy & cossts calculations for ICT & housing

	Number	Unit power	use duration	energy demand	PV power required	Battery capacity	PV module cost (crystalline)	PV module cost (thin film)	Battery cost	ICT equipment cost	PV system cost (w/cryst. Mod.)	PV system cost (with thin film mod.)	PV+ICT system cost (with cryst. mod.)	PV +ICT system cost (with thin film mod.)
	[Units]	[W]	[h/day]	[Wh/day]	[Wp]	[Ah]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]
Vijiji	10344	120	4	4965120	1103360	413760	5196825,60	2603929,60	542025,60	10344000,00	5738851,20	3145955,20	16082851,20	13489955,20
Mitaa	1755	120	4	842400	187200	70200	881712,00	441792,00	91962,00	1755000,00	973674,00	533754,00	2728674,00	2288754,00
Kata	2555	120	5	1533000	340667	127750	1604540,00	803973,33	167352,50	2555000,00	1771892,50	971325,83	4326892,50	3526325,83
Tarafa	516	120	6	371520	82560	30960	388857,60	194841,60	40557,60	516000,00	429415,20	235399,20	945415,20	751399,20
TOTAL	15170			7712040	1713787	642670	8071935,20	4044536,53	841897,70	15170000,00	8913832,90	4886434,23	24083832,90	20056434,23
TOTAL CHK					1713787	642670	8071935,20	4044536,53	841897,70	15170000,00	8913832,90	4886434,23	24083832,90	20056434,23

Local Government Administration Housing Energy Calculations

	Number	Unit Energy demand	use duration	Total energy demand	PV power required	Battery capacity	PV cost (crystalline)	PV cost (thin film)	Battery cost	Home appliances costs	PV system cost (w/cryst. Mod.)	PV system cost (with thin film mod.)	PV (cr) sys+Home Appl. cost	PV (thn-flm) syst+Home Appl.cost
	[Units]	[Wh/day]	[h/day]	[Wh/day]	[Wp]	[Ah]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]
Vijiji	10344	728	N/A	7530432	1673429,3	627536	7881852,16	3949293,23	822072,16	3103200,00	8703924,32	4771365,39	11807124,32	7874565,39
Mitaa	1755	728	N/A	1277640	283920,0	106470	1337263,20	670051,20	139475,70	526500,00	1476738,90	809526,90	2003238,90	1336026,90
Kata	2555	728	N/A	1860040	413342,2	155003,3	1946841,87	975487,64	203054,37	766500,00	2149896,23	1178542,01	2916396,23	1945042,01
Tarafa	516	728	N/A	375648	83477,3	31304	393178,24	197006,51	41008,24	154800,00	434186,48	238014,75	588986,48	392814,75
TOTAL	15170			11043760	2454168,9	920313,3	11559135,47	5791838,58	1205610,47	4551000,00	12764745,93	6997449,04	17315745,93	11548449,04
TOTAL CHK						920313,3	11559135,47	5791838,58	1205610,47	4551000,00	12764745,93	6997449,04	17315745,93	11548449,04
Total for ICT+Housing				**18755800**	**4167955,6**	**1562983**	**19631070,67**	**9836375,11**	**2047508,17**	**19721000,00**	**21678578,83**	**11883883,28**	**41399578,83**	**31604883,28**

8.7. Annex 5 Potential sources of finance for PV projects.

As stated in the thesis PV projects could better be presented in the framework of providing a particular service with PV serving as an energy source for successful implemented of that service. So the PV costs could only be taken as part of the costs of the whole project. A number of partner sources could come together with each partner supporting a part of the costs. In addition local resources such as land and labour could be involved and in this case even if these resources are not paid for their value must be acknowledged in a financial equivalent. With this in mind, then the potential sources of financial resources are as enumerated hereunder:

Sources of finance

Finance for the above mentioned purposes would have to be obtained from one or a combination of the following sources:

Internal sources:

1. Central government (grants, subventions, personnel salaries, allowances etc.)
2. Local governments (grants, subventions, personnel salaries, allowances, etc)
3. Local entrepreneurs (investment, publicity/goodwill, micro-credits, training) eg Zara Solar, of Mwanza Tanzania. (**Zara Solar 2007**) http://www.ashdenawards.org/files/2007_technical_summaries/Zara_2007_Technical_report.pdf (accessed 9 Jan 2008)
4. Local banks (in form of credits, publicity/goodwill investments)
5. Local non-governmental organisations (NGO’s) (cash, labour mobilization)
6. Local community based organisations (CBO’s) (cash, labour contributions)
7. Local religious organisations (cash, labour, mobilization and/or contributions)
8. Political parties (cash, labour mobilization and/or contribution)
9. Schools themselves (cash, labour mobilization and/or contribution)
10. Parents (cash, labour contributions)
11. Pupils (labour)
12. Local PV components/systems manufacturers (equipment, training)
13. Local representatives of foreign PV components/systems manufacturers (equipment, training)
14. Local Technology Incubation Programs

External sources:

15. Foreign governments(grants, loans) through bilateral and/or multilateral agreements
16. Foreign political parties eg The Greens (Europe), SPD (Germany),
17. Overseas cooperation/development agencies, eg GTZ, SIDA, NORAD, USAID, SenterNovem
18. International academic cooperation organisations eg DAAD, VLIR, SAREC
19. International organisations eg UN, EU,
20. Specialized UN departments eg UNEP, UNESCO, UNICEF, WHO, ILO, or specialized funds e g GEF,,
21. International Banks eg ADB, KfW, WB-IFC,
22. International RE entrepreneurs, eg LOH
23. Foreign manufacturers of PV components and/or systems, (grants or credits in form of their products for systems demonstration purposes)
24. International philanthropic organisations eg Bill& Melinda Gates Foundation, Bill Clinton Foundation, Africa 2000 (Jimmy Carter foundation).
25. International environmental foundations and lobbies eg Heinrich Boell Stiftung, Greenpeace,

26. Specialized RET funding organisations
27. Foreign/International religious organizations eg CARITAS,
28. Carbon trading (CDM) [last priority because this is too competitive with other cheaper carbon trading mechanisms eg forestry]
29. Foreign Technology Incubators

8.8. Annex 6: List of plants that can be used to generate energy (energycrops)

Energy plant species that can be grown to produce alternative fuels for use at Hybrid stations together with Photovoltaics (PV) include

Aleman Grass
Alfalfa
Annual Ryegrass
Argan Tree
Babassu Palm
Bamboo
Banana
Black Locust
Broom
Brown Beetle Grass
Buffalo Gourd
Cardoon
Cassava
Castor Oil Plant
Coconut Palm
Common Reed
Cordgrass
Cotton
Cuphea
Eucalyptus
Giant Knotweed
Giant Reed
Groundnut
Hemp
Jatropha
Jojoba
Kenaf
Leucaena
Lupins
Meadow Foxtail
Miscanthus
Neem Tree
Oil Palm
Olive Tree
Perennial Ryegrass
Pigeonpea
Poplar
Rape
Reed Canarygrass
Rocket
Root Chicory
Rosin Weed
Safflower
Safou
Salicornia
Sheabutter Tree
Sorghum (Fibre)
Sorghum (Sweet)
Sorrel
Soybean
Sugarcane
Sunflower
Sweet Potato
Switchgrass
Tall Fescue
Tall Grasses
Timothy
Topinambur
Water Hyacinth
White Foam
Willow
Cereals

- Barley
- Maize
- Oats
- Rye
- Triticale
- Wheat

Pseudocereals

- Amaranthus
- Buckwheat
- Quinoa

Microalgae

Source: El Bassam, N (1998); "Energy Plant Species", James & James

8.9. Annex 7: Some sources of further information on Solar Energy

(various solar energy organisations, associations, information services, and publishers)

General Info on RE & EE in Buildings:
http://www.bauherr.de

BOXER - Infodienst: Regenerative Energie
http://www.boxer99.de

CADDET - global information on commercial RE applications
http://www.caddet-re.org

Solar energy news-server
http://www.solar-news.de

EREN - Energy Efficiency and Renewable Energy Network (US Dept of Energy)
http://www.eren.doe.gov

Interactive Solar Energy supply advisor (*interaktiver Förderberater*)
http://www.solarfoerderung.de

James & James - International Environmental Science Publisher
http://www.jxj.com
(Publishers of Renewable Energy and Energy Efficiency literature).

PHOTON - The Solars electricity magazin
http://www.photon.de
PHOTON - Das Solarstrommagazin

PV Portal
http://www.pvportal.com

Renewable Energy On-Line Database
http://www.jxj.com/suppands/regenerg/index.html

REFOCUS Magazine (official publication of ISES)
http://www.re-focus.net

BINE - Bürgerinformation Neue Energietechniken, Fachinformationszentrum Karlsruhe
http://www.bine.info

German Renewable Energy Federation (BEE - Bundesverband erneuerbare Energien
http://www.bee-ev.de

German Solar Industry Association (BSW-Solar) Bundesverband Solarwirtschaft e.V..
the commercial arm of the German Federal Union of Solar Industries (BSi - Bundesverband Solarindustrie
http://www.bsi-solar.de)

Rural Electrification in Developing Countries department of BSi
http://www.rural-electrification.com/

German Information Portal for Renewable Energy
http://www.unendlich-viel-energie.de/en/homepage.html

German Energy Agency (DENA) - Deutsche Energie Agentur
http://www.deutsche-energie-agentur.de

German Society for Solar Energy (DGS) - Deutsche Gesellschaft für Sonnenenergie e.V.
http://www.dgs-solar.org

Berlin Chapter of DGS - Landesverband Berlin Brandenburg e.V.
http://www.dgs-berlin.de

Energie-Online
http://www.energie-online.de

EUROSOLAR
http://www.eurosolar.de

Renewable Energy Research Association (FVEE) (*Forschungsverband Erneuerbarenergen)*
http://www.fvee.de/
direct to PV related articles: http://www.fvee.de/forschung/forschungsthemen/photovoltaik/

Solar Energy research Association (FVS) (*Forschungsverband Solarenergie*)
http://www.fv-sonnenenergie.de

Forum for Future Energies, (*Forum für Zukunftsenergien e.V*)
http://www.zukunftsenergien.de

Hahn-Meitner-Institut, Berlin (HMI)
http://www.hmi.de

Energy Estimation / Calculation /Simulation Software

Dr Valentines Energy Software Co.
(www.valentin.de)

Building Energy Software Tools Directory (Database)
http://apps1.eere.energy.gov/buildings/tools_directory/

ICT and Open Source Software Development

This is a NASA Open Source for various software including those for PV
http://opensource.arc.nasa.gov/

Some ICT policy studies by UNDP http://www.opt-init.org/framework/pages/title.html

8.10. CURRICULUM VITAE

Kamugisha A.W. Byabato, Engineer and University Lecturer
Born 11- November - 1955, Bukoba, Tanzania

1977-1978	Study of Russian Language Leningrad Polytechnic Institute (Preparatory Faculty), Leningrad USSR
1977-1983	Study of Mining Engineering Leningrad G.V. Plekhanov Mining Institute, Leningrad USSR, now St. Petersburg, Russia Earned a Master of Science (with honours) degree in Mining Engineering
1984-1987	Work as Mining Engineer State Mining Corporation (STAMICO), Tanzania Start construction of the Kiwira Coal Mine Complex Construction of a 4km mine access road and bridge over the Kiwira river, underground preparatory works and mine surface buildings including mine operation buildings, workshops, offices, coal washing plant, coal fired power station and workers' residential township with social facilities (hospital, schools and public administration buildings).
Jul-Sept. 1987	Study of French Language At the Centre for Applied Lingustics (CLA), University of Franche-Comte, Besançon France
1987-1988	Study of Mining Technology and Development of Underground Mineral Resources Center for Higher Studies in Mining Technology (CESTEMIN), Nancy School of Mines; Nacy, France Earned two French degrees *Diplôme d'Ingénieur Expert en Techniques Minières (Dip. Ing.Exp.)* *Diplôme d'Etudes Supérieures Spécialisées (DESS)* of the National Polytechnic Institute of Lorraine (INPL)
1988-1991	Promoted to Senior Mining Engineer Continue with operations at Kiwira Coal Mine.
Jan- June 1992	Brief working stint as Technical Instructor Government Technical College, Kibungo, Rwanda
1992- To date	Lecturer for Building Technology, Building Services Architecture Department, Ardhi Institute, renamed University College of Lands and Architectural studies (UCLAS) now Ardhi University, Dar es Salaam, Tanzania.
Jan-Mar. 2001	Visiting scholar University of Florida, Gainesville, USA
Jul 2004 To-date	PhD candidate, Chair of Environmental Architecture Dortmund University of Technology, Dortmund, Germany. Deeper studies and research in Energy-Efficiency and Application of Renewable Energy Technologies (RETs) in buildings.
2007 To-date	Established the Tanzania Energy Research Institute, in Dar es Salaam, Tanzania

Languages:
Conversant with the following languages:
English, French, German, Russian, Kiswahili, Ruhaya