Sustainable Development: Energy Matters*

Pushpendra K. Jain

Professor of Physics, University of Botswana,
P Bag 0022, Gaborone, Botswana

Ph. (W): (+267) 355 2136, (C): (+267) 7151 9489
Fax: (+267) 318 5097 (Attn. Prof. Jain), Email: <jainpk@mopipi.ub.bw>

*Professorial Inaugural Lecture, Wednesday, March 31, 2010, University of Botswana.

Abstract: The lecture deals with the role of energy in sustainable development of human society, and related energy issues. Social, cultural and technological development of human society is intertwined with the discovery and development of energy sources. The journey of development began over a million years ago with the discovery of fire which continues unabated even today needing ever more energy to fuel the inflationary cycle of development. In the first part of the lecture the role of energy in development is reviewed in relation to the development of energy sources and their use. In the second part of the lecture energy consumption for various regions of the world is analyzed and energy indicators of development are identified. Vast disparity between the developed and developing countries is reflected in their energy consumption patterns. As developing countries strive to join the ranks of developed countries, the developed ones endeavor not only to sustain their development but also to achieve higher levels of the quality of life for their people. This together with the growing population has led to an ever increasing consumption of energy which at present is supplied by non-renewable sources, predominantly fossil fuels. This in turn has led to degradation of our atmosphere, land and water. The third part of the lecture emphasizes on the need to develop new and renewable sources of clean energy which shall have the potential to sustainably supply the energy needs of future while preserving our environment. The concluding section of the lecture focuses on energy sustainability and security for the generations to come.

Key Words: Sustainable development, Energy sources, Renewable energy, Energy demand, Energy supply, Energy security, Energy sustainability.

1. INTRODUCTION

Title of the lecture, *Sustainable Development: Energy Matters* comprises two phrases of two words each, 'Sustainable Development' and 'Energy Matters', implying an intimate relationship between the two parts. In order to appreciate this relationship, we begin by defining the four words.

Sustainability is best defined by the Brundtland World Commission on Environment and Development as: "*Human endeavor which meets the needs of the current generation without jeopardizing the needs of future generations"* [1]. In not so distant a past indiscrete exploitation of our resources and the environment was a globally accepted norm. However, over the past quarter of a century or so, with the awareness of fast depleting resources and degrading environment, sustainability has become an ever growing concern in all human activities and goals that involve the use of natural resources including energy and the environment. In the context of energy, sustainability can be stated as: *"Energy that is produced and used in ways that will support long-term human development in all social, economic and environmental dimensions"* [2].

Development is *"An ongoing process to achieve industrialization resulting in higher gross domestic product and increased per capita consumption of commercial energy"*. Increased access to education, health care, clean water, and expanded communication and transportation networks are some of the natural outcomes of development, though the benefits are not necessarily evenly distributed throughout the population.

Physics text books define ***Energy*** as *"an entity needed to do work"* [3]. Energy, for example electricity and heat, is used to operate machines in our industries and factories, to run the transport, and to operate household gadgets.

It is derived from a variety of sources namely fire wood, coal, petroleum products, nuclear fuel, sun, wind etc., and its production, distribution and usage directly affect the environment.

In the present context, ***Matters*** has a dual meaning: *(i) Issues related to,* and *(ii) Plays a role.* Thus, the phrase ***Energy Matters*** has double meaning: *(i) Issues related to energy,* and *(ii) Energy plays a role.*

With this understanding of definitions, and putting both parts of the title together, it alludes to: ***"Energy issues and the role of energy in sustainable development".*** These are discussed in the lecture under the following headings:

(i) Energy and development.
(ii) Energy sources.
(iii) Solar energy.
(iv) Energy demand, consumption and economic development.
(v) Environmental impact of energy use.
(vi) Energy indicators of development.
(vii) Energy security and sustainability.

2. ENERGY AND DEVELOPMENT

Pivotal role of energy in development is exemplified by the following quotations [2] selected from hundreds of similar quotations.

> *"It is clear that there is some difference between ends: some ends are* ***energia*** *(energy), while others are products which are additional to the* ***energia****".*
>
> \- Aristotle, Greek Philosopher (ca 325 BC).

> *"Fire is the best of servants, but what a master".*
>
> \- Thomas Carlyle, British author (1843).

> *"Affordable energy in ample quantities is the lifeblood of the industrial societies and a prerequisite for the economic development of others".*
>
> \- Eugene Odum, US Physicist (2001).

These three quotations, spread over two and a half millennia, point to the following basic facts about the relationship between energy and development:

- Energy is central to all production (industrial) activities which in turn lead to economic development.
- Fire, known to mankind since prehistoric time, remains a key role player in meeting the human energy needs even in the present times, for example be it the (thermal) generation of power or the operation of our transport.

There are many aspects of human development namely social, cultural, economic, industrial, technological etc. Here we consider an oversimplified scenario of social, cultural and technological development of human society from the energy perspective. Economic development shall be linked to energy demand and consumption through industrial development in a later section of the lecture.

2.1. Social, Cultural and Technological Development

The journey of social, cultural, and technological development of human race began with the discovery of the production, and controlled use of fire 200,000 to 400,000 years ago [4]. Burnt bones, bones treated to temperatures of 200 to 300 °C, which is far above the temperature of bush fire, and bone tools found in the Sterkfontein caves in South Africa suggest that fire had been used by our ancestors as early as 1 million years ago.

The journey of development that started with the taming of fire continues even to this day and remains tied-up to the development and use of energy sources. Some major milestones in this journey are:

- Prior to the discovery of fire, the only source of energy known to prehistoric man was the sun which provided light and warmth. Perhaps a limited use of solar energy was also made to dry and preserve meat and food. Life revolved around the cycle of the sun and the daily activities were confined to day-light hours. Nights were cold, and dark, dreaded of attack from wild animals. People lived in caves for protection. Their habitat was confined to warmer climates. Archeological findings also suggest that the warm continent of Africa is the *Cradle of Mankind.*
- Prehistoric man was familiar with wild, natural fire from lightening, volcanic eruption etc., but was not able to produce and control it at will. While he feared wild fire, he was aware of its utility as a source of heat, light and protection from wild animals. He perhaps also made opportunistic use of wild fire in consuming burnt and roasted animals and wild food. It is this awareness which might have inspired early man to *discover* fire.
- The *discovery of fire* and the ability to produce and control it provided light at night, heat to keep warm at night and on cold winter days, and protection from predators. This would have resulted in the development of night-time activities around fire such as singing, dancing and storytelling, and would have led to migration to colder climates. In fact, discovery of fire led to an unparalleled revolution in the history of mankind which can be seen even today in the use of fire in industry, power generation, and the transport sector.
- Ability to tame animals to ride and carry load put another important source of energy, the animal power, at the disposal of mankind. This would have increased the range of migration and exploration. Hunting and agricultural practices would have changed. Ownership of animals, perhaps, was also the emergence of materialistic societies.
- Invention of wheel gave birth to animal driven carriages and it forever changed the whole concept of mobility. Bigger loads and number of people could be transported longer distances and faster using fewer animals. This was the beginning of the era of energy efficiency, *i.e.*, having more work done with the use of less energy (animal power). Thus, energy efficiency is not a new concept. The quest for energy efficiency is rooted in the invention of the wheel although the phrase *"energy efficiency"* was not coined and did not come in common use till as late as the last quarter of the 20th century.
- Another important *"energy - milestone"* on the road to development is the harnessing of the wind and the tidal power, and the discovery of sail boats. This further extended the range of mobility. Migration across oceans, and international trade and cultural exchange developed.
- Discovery of coal and its use as a preferred, convenient and abundant source of thermal energy together with the invention of the steam engine set stage for the industrial revolution. The first industrial revolution starting in the latter half of the 18th century (late 1700s) to the early 19th century (around 1850s) was a result of a combination of ongoing complex socio-political processes, but the role of energy and the scientific and technological discoveries stand out as the main catalyst without which industrialization would not have happened.
- The second industrial revolution from 1860s to the early 1900s was onset with the use of liquid fuels, the oil, and the invention of the internal combustion engine. This phase of development was rapidly propelled forward with power generation and distribution capabilities and the invention of electrical motors and machines. This period also saw a growing energy demand from the domestic sector driven by improved living standards in the developed countries. To meet the demand new energy sources and technologies were discovered. A particular mention should be made of the nuclear energy which became commercially available in the mid-1950s.
- The third industrial revolution started in the late 1900s with tremendous developments in mass communication, information technologies, and space exploration and technologies. There has also been a rapid development in the transport sector. All modes of fast moving motorized ground transport, planes crisscrossing the skies, and large ocean liners sailing the ocean have become the order of the day. Most consumer goods are now mass produces in factories. To meet the ever increasing global demand of cheaply produced quality goods and services, there has been a trend of relocating of manufacturing and

off-shoring of services to the underdeveloped, third-world countries which have lower labour and overhead costs, leading to industrialization of those regions. There has been a phenomenal steady growth in energy demand to power factories and the transport. To fuel this new wave of development of the underdeveloped parts of the world and to extend energy services to thus far energy-destitutes to improve their living conditions, we not only need new, affordable and abundant sources of energy but they should also be environment compliant. As a result, development and promotion of new and renewable sources of energy such as solar, wind, tidal, geothermal etc., and energy efficiency and conservation have gained momentum. Thus the mankind's quest for energy that started with the discovery of fire about a million years ago still goes on for new sources of energy to supply ever increasing demand.

From this brief overview of the development of human society since pre-historic time, it goes without saying that energy has been the key driver of development. In the present-day-world as well, our observation tells us that the countries and the societies that lack access to energy lack development. This has resulted in the polarization of the world into developed, developing and underdeveloped countries with a vast disparity between the quality of life and the standard of living of their people. To mitigate this disparity, developmental goals have been initiated at global as well as national levels, for example the *Millennium Development Goals (MDGs)* [5] for global poverty reduction and human development by 2015 adopted by the 2000 United Nations General Assembly, and the *Vision 2016: Towards Prosperity for All* [6] of the Republic of Botswana. Energy remains an important ingredient for the realization of these development goals, for example:

- *To reduce universal poverty and hunger, (MDG 1):* Energy is required for job creation, self-employment, farming, and food processing and distribution.
- *Universal primary education (MDG 2)* cannot be achieved without energy for lighting in class rooms, teachers' residences, and students' hostels at the least. Energy is also needed to improve the quality of teaching and learning through the use of audio-visual equipment, computers and to teach laboratory courses.
- Can we hope to *reduce child and mother mortality at birth (MDG 4*) and *improve health services (MDG 5* and *6)* without energy for lighting, sanitation, refrigeration and storage of life-saving drugs, and for residences of the medical staff and health workers to attract them to work in remote and rural clinics and health posts.

Thus, energy is a fundamental prerequisite for the realization of all development initiatives. It is more so because the development goals are mostly targeted at underdeveloped communities. Such communities also lack access to adequate energy resources which itself is responsible for their underdevelopment to begin with. Even if some partial success could be achieved initially in realization of some of the development goals, it will be difficult to sustain those achievements and make further progress without access to sustainable energy.

3. ENERGY SOURCES

Most abundant primary energy sources used globally at present are wood and the fossil fuels, *i.e.,* coal, oil products and natural gas. Their demand and consumption patterns reflect the economic development of the respective consumer societies. Nuclear, hydro power, solar, wind, geothermal, tidal etc. contribute only a small fraction of the total energy consumption. Electrical power is also a major source of energy, but it is a *manmade*, secondary source of energy produced by fuel conversion from primary sources of energy, namely fossil fuels, hydro and nuclear power.

3.1 Classification of Energy Sources

A number of different schemes are used to classify energy sources which depend upon their means of production, procurement, distribution, usage, lifetime of their global reserves and the cost. Commonly used classification schemes are as follows:

Scheme 1: As per this scheme, the energy sources are classified into the following two categories:

(i) *Traditional or Low grade energy sources:* These sources have low commercial value. They are available either free of cost or at a very little cost. They lack formal network of procurement and distribution. They are used as a source of thermal energy to meet basic energy requirement for cooking, heating and lighting by the poor, remote and rural populations which lack development, and economic means to use high cost energy sources. These energy sources are not used for industrial application or for electricity generation.

(ii) *Commercial or High grade energy sources* are the fuels of choice for industrial use, power generation, transport sector and to sustain life-style of luxury. They are produced and distributed through a formal infrastructure at a cost to consumer.

Scheme 2: Under this scheme also the energy sources are grouped into two categories as follows:

(i) *Non-renewable sources of energy:* They have limited reserves. Once consumed, they are irreplaceable. With continued consumption their reserves diminish, and will eventually be exhausted.

(ii) *Renewable sources of energy* have inexhaustible reserves and their supply will never run out even though their rate of consumption may grow with time. Fuels that regenerate, even though their supply at a given time may be limited, are also regarded as renewable.

Scheme 3: The two categories of fuel classification under this scheme are:

(i) *Fossil fuels:* These fuels have been produced through fossilization of ancient biomass over millions of years. They are also non-renewable sources of energy.

(ii) *Non-fossil fuels:* These fuels are either generated by human intervention or they generate themselves. They could be either renewable or non-renewable depending on how they are produced.

The following sub-sections list the energy sources under various categorizations, and their direct and indirect uses. Because of the different classification schemes, each energy source belongs to more than one category of fuels.

3.2 Traditional Energy Sources

These include:

- ***Wood fuel*** is used as a source of thermal energy for cooking, heating, and lighting. It is a non-fossil fuel, and non-renewable under normal usage. However, with sustainable harvesting and reforestation it can be regarded as renewable. Through fuel conversion process it can be transformed into charcoal, which is a commercial, higher grade of fuel.
- ***Cattle dung:*** Dried dung cakes are used as a source of heat energy. It is a non-fossil, renewable fuel. Cattle dung slurry is used to produce bio-gas in a bio-mass digester which is a higher grade of energy source used for cooking, heating and lighting.
- ***Agricultural waste*** is a source of thermal energy and bio-gas production. Could be regarded as a renewable fuel.
- ***Animal power*** is used as means of transport for people and goods either directly loaded on the back of the animal or by using animal pulled carriages. In the agriculture sector they are used to plough the fields, pull water from wells, and to turn traditional farm machinery. Here it is worth noting, as has also been stated earlier, that the use of animal-pulled carriages, as against carrying load on the animal back, is an example of *energy efficiency* practiced ever since the invention of the wheel, much before the term '*energy efficiency*' was coined by scientists and engineers and came in common use in recent times. In fact, prior to the oil crisis of 1972, energy efficiency and energy conservation were paid very little attention.
- ***Solar energy*** when used directly as a source of heat to keep warm, and to dry meat and produce as has been the case since prehistoric times is also a traditional source of energy which is renewable.

3.3 Fossil Fuels

These include coal, oil and natural gas. They have been produced in nature through fossilization of ancient vegetation and marine life over millions of years under intense pressure and heat in the interior of the earth. Fossil fuels are non-renewable, commercial fuels. Infrastructure for their production, transportation and distribution is well developed. The world economy at present is propelled by fossil fuels. They are the preferred source of energy for a wide range of industrial and non-industrial applications and power generation. In 2007, 81.4% of the total world primary energy was provided by fossil fuels [7]. A large fraction of them, mainly coal followed by natural gas was used to generate 68% of the total world electricity [7]. The transport sector almost exclusively uses oil products with the exception of some old ships and railway trains that use coal.

3.4 Renewable Energy Sources

Solar, wind, tidal, geothermal, bio-fuel and biogas are the renewable sources of energy (Figure 1). Reserves of solar, wind, tidal and geothermal sources of energy are inexhaustible. They never run out of supply irrespective of their continued and growing rate of consumption. Biogas and bio-fuel are renewable because their sources of production regenerate. Hydro power from a natural perennial source without significant change in the volume of flow with time is also renewable and so is the wood fuel from sustainable forestation and harvesting cycle.

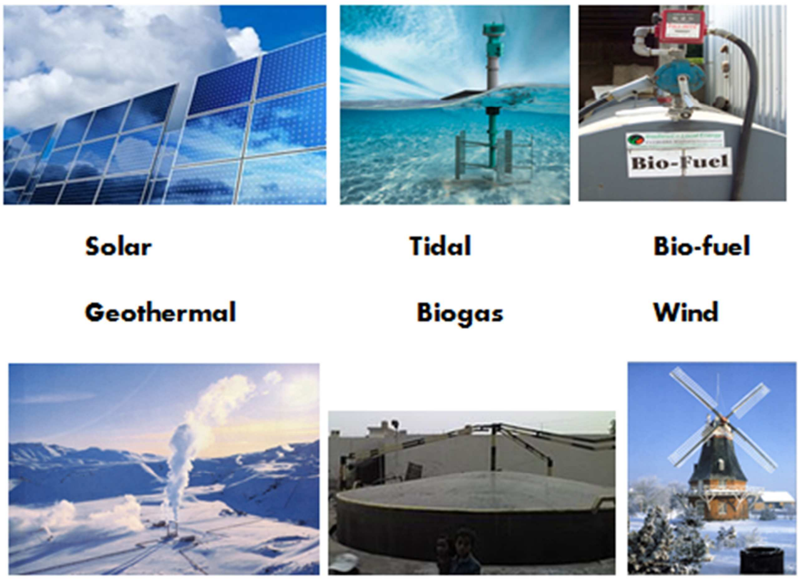

Figure 1: Some examples of renewable energy sources.

When used as-is, applications of solar, wind, tidal and geothermal energy are limited to low-grade energy usage, and the work - energy efficiency is significantly low, for example the use of solar radiation to keep warm in cold climate or to dry produce, and the use of wind energy to propel a sail boat. It is only when used in conjunction with appropriate technologies; these energy sources have the potential to make significant contribution to the energy supply for industrial and general-use applications in the context of development. The examples are electrical power generation from solar, wind and tidal energy sources; high temperature heat generation from solar and geothermal sources for industrial heat application or for power generation. Common applications of biogas are limited to lighting, cooking and heating. Bio-fuel is an oil substitute and is used to blend with natural oil.

Hydro-power has been used as-is for centuries to power water-wheel for the grinding of grain. However, its greatest potential as a modern and significant source of energy lies in the hydro–power generation (Figure 2) that contributed 15.6% to the total world electricity generation in 2007 [7].

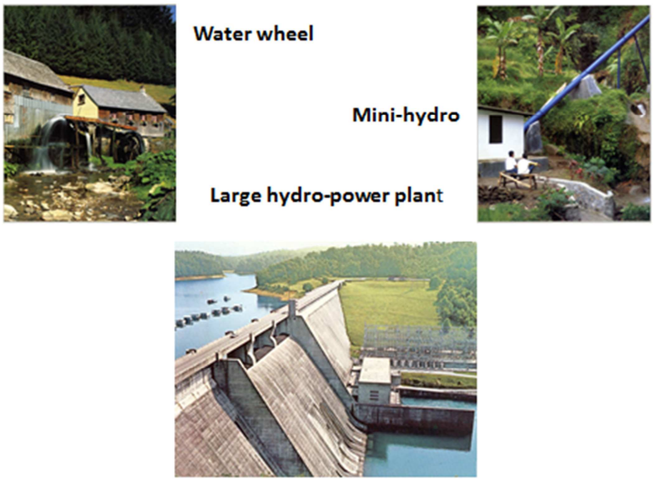

Figure 2: Applications of hydro-power:
Water wheel and mini and large hydro-power projects.

3.5 Fuel Conversion

Fuel conversion is the transformation of one form of energy source to another form of energy or energy source with the aid of fuel conversion technologies. Electricity is a typical example of fuel conversion which is not a primary energy source, rather a man-made form of energy. It is generated from a variety of energy sources such as fossil fuels (coal, oil, and natural gas), nuclear fuels, hydro-power, and solar, wind, tidal and geothermal energies. It can be termed as renewable if the primary input energy sources are renewable for example solar, wind, hydro etc., and it is non-renewable if the sources used to generate it are non-renewable for example coal, oil and gas. Electricity is the most convenient form of energy because of the ease of its transmission and distribution to consumers. At the consumer end it can easily be converted to other forms of energy or deployed to do any form of work by using appropriate motors, machines and technologies which are freely and commercially available. This makes electricity the most desirable commercial energy of the highest grade. However, because of the high generation, transmission and distribution costs it is not accessible to a large number of consumers in remote and rural areas in developing countries and it is not an affordable option for poor consumers.

Figure 3: Because of the ease of transmission and distribution,
electricity is the most convenient form of energy.

Charcoal is another example of fuel conversion which is produced from controlled combustion of wood under controlled air supply. The end product is an easily combustible, dark soft coal used for heating and cooking. Because of the ease of packaging, transportation and distribution it is a more preferred source of thermal energy than wood. Because of the costs involved in production and distribution it is a commercial source as against wood-fuel which is generally freely harvested by rural consumers. Same environmental implications namely deforestation and desertification are associated with the use of charcoal as is the case with the use of wood-fuel.

Figure 4: Charcoal production is controlled combustion of wood under controlled air supply.

3.6 Other Energy Sources and Technologies

There are a number of energy sources and technologies, some of which are well developed and have been in large scale usage for decades while the others are either in limited use or are at various stages of research and development. Without going into details, the energy sources and technology which have been in large scale usage are: nuclear fusion energy from fissionable heavy atoms for example Uranium; peat, tight and tar sands and shale which are fossil fuels. Sources and technologies that are in either limited use or at different stages of research and development are: waste-dump gas, hydrogen, fuel cells, MHD generators, combined power and heat cycle (CPH). Energy from nuclear fusion of light atoms for example Hydrogen is at advanced stage of R&D. When commercially available, it will put an inexhaustible source of clean energy at the disposal of mankind.

4. SOLAR ENERGY

Amongst the renewable energy sources cited earlier, solar energy has the largest potential in Botswana, and has been in limited use since early nineteen eighties. It is also most relevant to Botswana because of excellent solar conditions throughout the country. Like anywhere else, in Botswana it is used for lighting, space and water heating, refrigeration, water pumping, telecommunication, broadcasting and village electrification. Besides, solar energy resource, and systems and devices have been the research area of my (the speaker/ author) interest for the past 35+ years to which I have made many contributions. We, therefore, devote this section of lecture to discuss various aspects of solar energy.

Artists' impressions of the sun from different cultures and periods (Figure 5) signify that sun has been globally recognized through the ages as a sustainer of life. Direct solar energy has been used as a source of warmth and light since the first appearance of man on the earth.

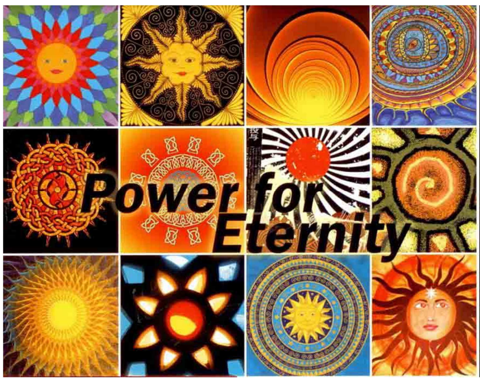

Figure 5: Sun has been globally recognized through the ages as a sustainer of life.

In modern times, in an energy hungry world we are interested in more efficient use of solar energy through the intervention of appropriate technologies. All solar energy devices are based on one of the two technologies. These are:

- *Solar thermal technology* that converts solar energy into heat energy, and
- *Solar photovoltaic (PV) technology* that directly converts solar energy into DC (Direct Current) electricity.

There are also hybrid systems which make use of both the technologies. Both, thermal as well as PV devices could either be non-concentrating or concentrating.

Non-concentrating devices use as-received, directly incident solar radiation. These devices are installed at a fixed optimum North-South orientation for a given location. To accommodate North-South seasonal motion of the sun, small seasonal North-South adjustment to orientation of the devices would seasonally improve their performance, but it is not crucial and is generally not done.

In a concentrating solar device, solar radiation collected from a large area is focused on to the device of small area. The ratio of the area of radiation collection to the area of the device gives the concentration ratio and it is expressed as number of suns. For example, non-concentration device are one sun devices.

The concentrating devices must continually track the motion of the sun so that the solar radiation remains focused on the device throughout the day. For up to 5-sun concentration single axis tracking about a North-South axis is adequate, but for higher concentration two axes tracking is essential.

Common applications of solar energy for lighting using PV solar panels and, and space and water heating with (thermal) solar collectors are well known to most of our audience. In the interest of time we shall not delve into their details. Instead, here we focus briefly on some of the less known applications, and discuss other relevant aspects of solar energy applications.

4.1 Central Receiving Systems

A central receiver system (CRS) also known as power tower is used to produce extremely high temperature heat which in turn is used either to produce high temperature steam for power generation or for metallurgical or other high temperature industrial applications. A large number of large area plane mirrors mounted in a plain field of several square kilometer area reflect solar radiation on to a central receiver mounted on a high tower (Figure 6). The plane mirrors, called heliostats, continuously track the sun to maintain focus on the receiver. CRSs of up to 10 MWe capacities have been in use in a number of countries for nearly three decades and their numbers have grown rapidly in recent years.

Figure 6: Tracking plane mirrors mounted in a large field reflect solar radiation on to a central receiver atop a tower.

Amongst the earliest examples of a CRS generation facility is a 10 MWe power tower in Barstow, California, USA which became operational in 1982. It has 1818 heliostat of 39.9 m^2 area each. The tower height is 80 *m*.

Heat is stored in a tank filled with 6798 tons of rock and the heat transfer oil. The power plant can generate electricity at 7 MW for up to 4 hours from the stored heat [8]

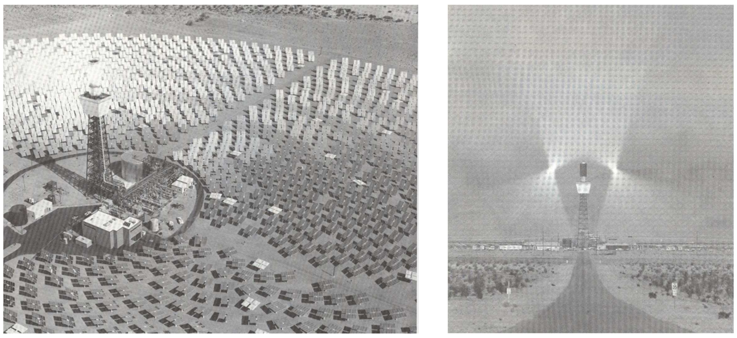

Figure 7: Two views of the 10 MWe solar thermal central receiver power tower in Barstow, California USA constructed in 1982.

Some other CRSs power projects that were implemented during the same period include [8]:

- A 1000 kWe CRS, the Eurelios, in Sicily, Italy was first connected to grid in 1981.
- A 1000 kWe CRS power plant, the Sunshine, in Shikoku, Japan started generating power in 1981.
- A 500 kWe CRS power plant and a 500 kWe distributed collector electrical generating plant began operation in southern Spain in 1981.
- A 1200 kWe CRS power plant, CESA, in Almeria became operational in 1983.
- A 2000 kWe CRS, Themis power tower near Targassonne, Southern France, went in operation in 1983 [9].

Some of the CRS power towers completed in recent years include [10, 11]:

- PS20 solar power tower of 20 MW in Spain was completed in 2009.
- Sierra Sun Tower of 5 MW in the US was completed in 2009.
- Jülich Solar Tower of 1.5 MW capacity in Germany was completed in 2008.
- The 11 MWe PS10 solar power tower in Spain was completed in 2006.

4.2 Passive Solar Architecture

Thermal comfort of buildings for a comfortable living and for improved working environment is a key concern for the residents and the workers alike. In the high cost housing sector and the public and commercial buildings this is conventionally achieved with the use of space-conditioning devices. However, in the housing sector in developing countries in general and the low cost housing globally the use of space conditioning devices is well beyond the financial means of the residents because of the high initial cost of the devices and the recurrent cost of electricity to operate them. In developing countries power may not even be available in the remote and rural areas, or the power supply may be unreliable due to frequent power failures and cuts. Alternative option to improve the thermal comfort of a building is the passive solar architecture whereby optimum use of solar energy is made by controlled direct solar gain in the building, and by selective absorption of solar energy and controlled release of the stored heat energy. These objectives are achieved by implementing appropriate design considerations, for example building orientation, window area and placement, and by using appropriate construction materials for example the exterior surface colour, thermal insulation and the thermal mass of the structure. A passive solar building incorporating appropriate design parameters has an improved indoors thermal comfort without the use of space conditioning devices at no or very little extra cost of construction. Use of natural lighting during the day results in additional energy savings. A number of buildings in Botswana have been constructed on the principles of passive solar architecture though they also have some active features. The Botswana Technology Center headquarters in Gaborone is one such building.

The author had simulated annual heating and cooling loads for a medium cost BHC (Botswana Housing Corporation) house to maintain an ideal indoor thermal comfort with the use of space conditioning devices by changing some of the design parameters of the house [12, 13]. The parameters studied were the exterior wall colour, thermal insulation, thermal mass, window area and placement, and a number of different values for each parameter were considered. Taking as-constructed house as the base house, percentage changes in the cooling and heating loads to maintain ideal thermal comfort throughout the year for each case of simulation with changed design parameter are shown in Figure 8 [12]. Decrease in the space conditioning loads signifies an improvement in the thermal comfort of the house in comparison to the base case without the use of space conditioning devices. Likewise, an increase of the space conditioning loads signifies just the opposite. Lastly, the best scenarios for each design parameter which resulted in the maximum decrease in the space conditioning loads were combined in one single simulation, termed as the best case scenario for the house. The last two bars in Figure 8 show the percentage changes in the annual heating and cooling loads for the best case scenario. We note that for the best case scenario there is 60% energy saving in the heating load during winter months, and there is 30% energy saving in the summer cooling load compared to the base case house if space conditioning devices were to be used [12]. In simple terms this means that if no space conditioning devices were used (as is generally the case in the housing sector in developing countries), the thermal comfort of the best case scenario house shall be 60% better during winter months and there will be 30% improvement in thermal comfort during the hot summer months. Simulation of indoor temperatures without the use of space conditioning devices also predicted significant improvement in the thermal comfort (temperatures) of the house for the best case scenario [14].

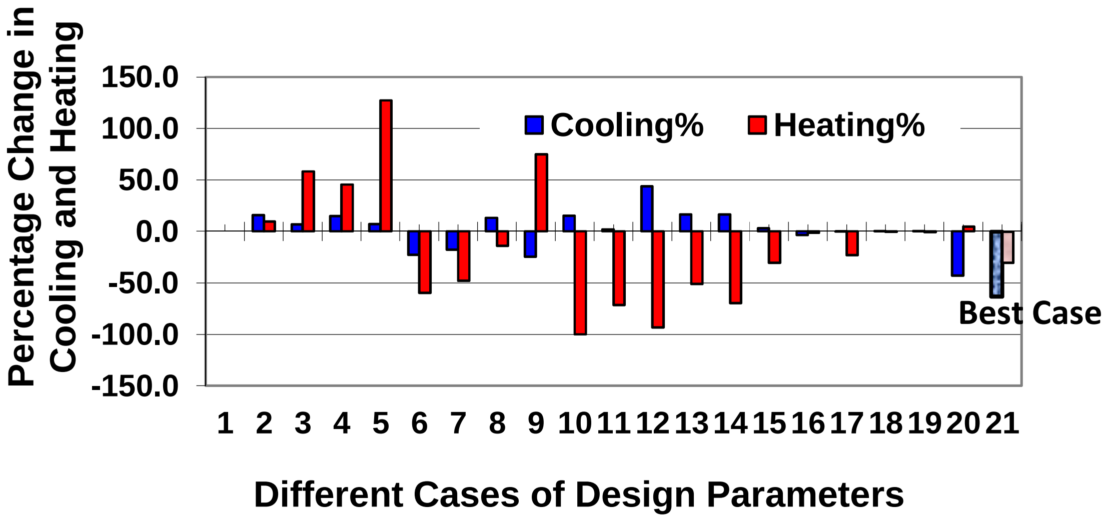

Figure 8: Percentage change in the annual cooling and heating loads for changes in various design parameter of the house to maintain optimum indoor thermal comfort.

4.3 Solar Radiation Simulation

Solar radiation data for the general location where the solar devices are to be deployed is essential for sizing of solar system for specific application. Where measured data is not available, one either uses data from a climatically identical location or generates it by simulation and modeling. The author has developed a number of modeling and simulation techniques in collaboration with other colleagues which include: atmospheric transmittance models [15], monovariate ARIMA models [16], and bivariate ARIMA models correlating extremum temperatures and solar radiation [17, 18], and correlating sunshine duration and solar radiation [17, 19].

Figure (9) shows mean monthly measured maximum and minimum temperatures and solar radiation for seven locations across Botswana [18, 20]. We note that the variation of solar radiation during the year follows the same pattern as the variation of the extremum temperatures for all the locations. This observation formed the basis of our bivariate ARIMA model that correlates extremum temperatures and the solar radiation [17, 18].

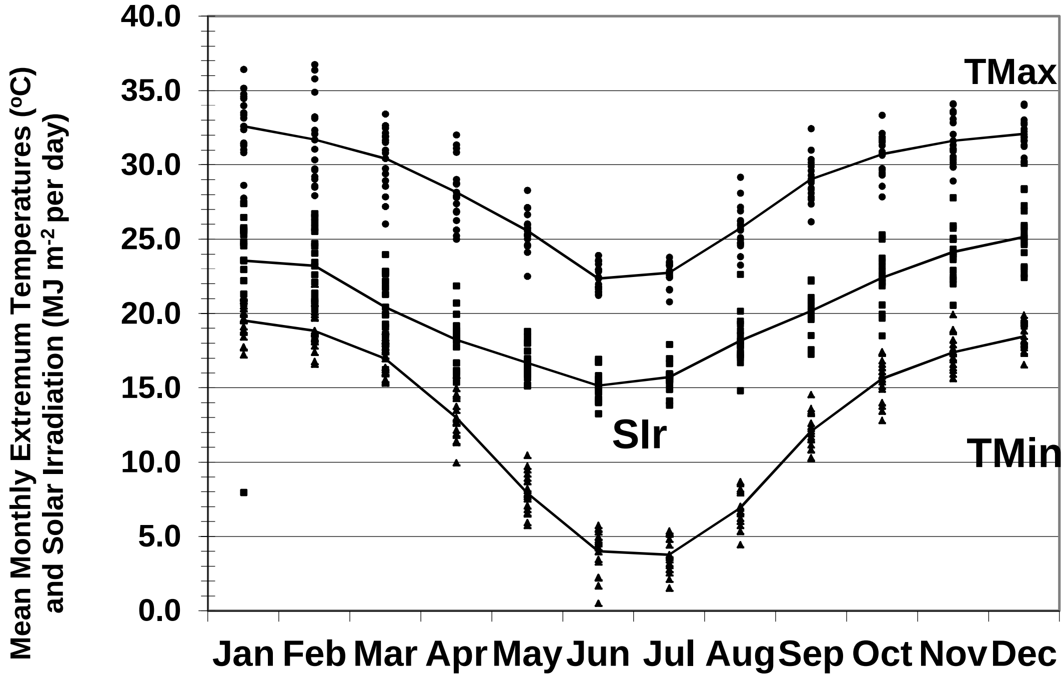

Figure 9: Mean monthly maximum (TMax) and minimum (TMin) temperatures and solar irradiation (SIr) for seven locations in Botswana.

4.4 Global Solar Potential

Solar energy is the most abundant source of energy distributed evenly throughout the world including the most inaccessible remote areas. Figure (10) [21] shows the global distribution of solar energy where the shades of red represent higher intensity of radiation and shades of blue correspond to lower intensity. If only 7% of the total area of six deserts shown in the figure as black dots is covered with only 8% efficient solar PV devices, the devices will produce 13,567 Mtoe (Million ton of oil equivalent) electricity annually, whereas the total world energy consumption in 2006 was 11,741 Mtoe [21]. Thus, the power generated by the devices will exceed the world energy consumption by 15.6%. The name, location and area of the seven deserts, area and percentage of area of each desert proposed to be covered by PV devices, and the totals of areas are detailed in Table (1) [21], and shown graphically in Figure (11).

This raises some pertinent questions:

- If solar energy is so abundant and has such a vast potential why it is not exploited to its full potential?
- Why the global contribution of solar energy stands only around 1%?
- Why is there energy crisis, and why does the cost of fuels continue to soar whereas free energy from sun remains lying idle?
- What are we waiting for?

The answer to all these questions lies in the cost of PV power production discussed in the next sub-section.

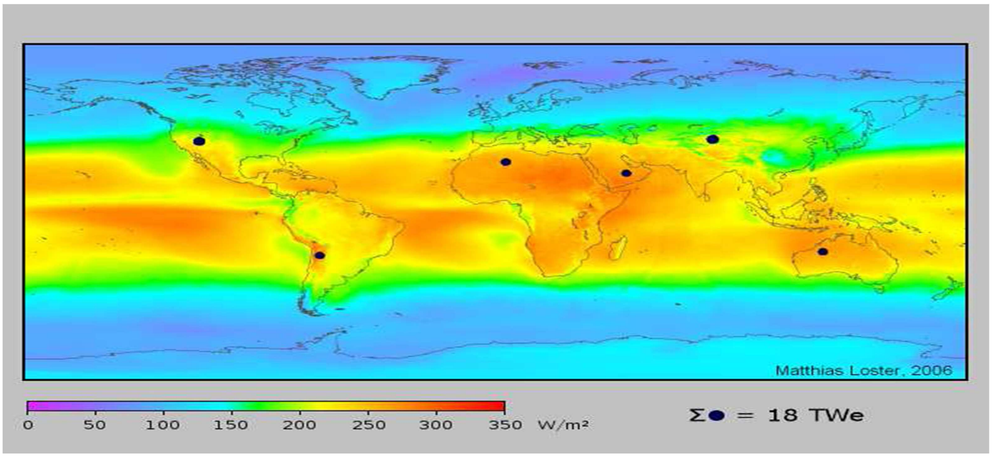

Figure 10: Global distribution of the intensity of solar irradiation.

Table 1: Location and area of the six deserts (shown as black dots in Figure 10), area and the percentage of their total area that needs to be covered with PV devices to generate more than the total energy consumption in 2006.

Desert name/ Location	Desert area (km^2)	Proposed Area covered (km^2)	Percent area covered
Sahara/ Africa	9,064,960	144,231	1.6
Central sandy/ Australia	388,500	141,509	36.4
Takla Makan/ China	271,950	178,571	65.7
Arabian/ Middle East	2,589,910	138,889	5.4
Atacama/ S. America	139,860	136,364	97.5
Great Basin/ USA	492,100	170,455	34.6
TOTAL	**12,947,280**	**910,019**	**7.0**

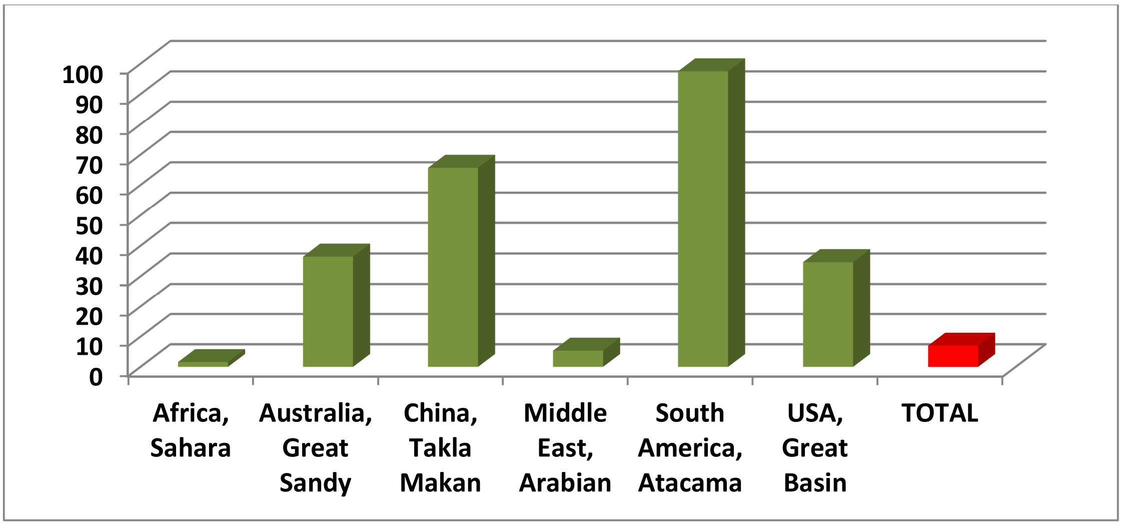

Figure 11: Percentage of the areas of six deserts in Figure 10, and Table 1 that will produce more than the total energy consumed in 2006.

4.5 Comparative Cost of RE-Power Generation

Figure 12 [22] shows the range of per unit wholesale and retail consumer prices of power generated from conventional primary energy sources and technologies (vertical bars), and per unit cost of power generated from various renewable energy sources (horizontal bars). We note that solar-PV power generation is the costliest option. It's per unit cost starts at the maximum retail price of conventional power and could be as high as 3 times the maximum retail price or higher depending on the technology and materials used. Although there is no cost of fuel for solar power generation, the technologies and materials used for the devices carry a very high cost. This puts the solar power generation at a big disadvantage in a highly competitive commercial enterprise of power generation. Unless the costs of solar devices and the materials come down drastically, the solar power option shall remain open only to specialized, remote and emergency applications. At this stage we ask: What is being done on the research and development front to bring down the cost of PV power generation, and to what extent such efforts are bearing fruit? We answer this question in the following sub-section.

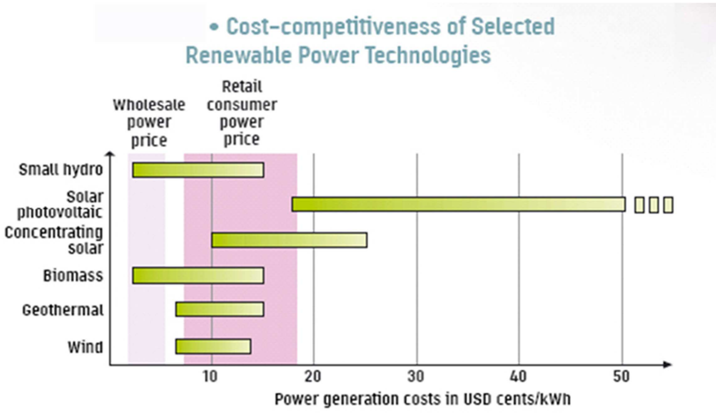

Figure 12: Comparative per unit cost of RE-power generation, and the current wholesale and retail per unit power price.

4.6 Efficiency of PV Devices from different Materials and Technologies

Extensive research and development is going on to improve the conversion efficiency of PV devices, and to bring down their cost with the use of different materials and technologies. Best lab-conversion efficiencies of various types of PV devices from 1975 to present are shown in Figure 13 [23].

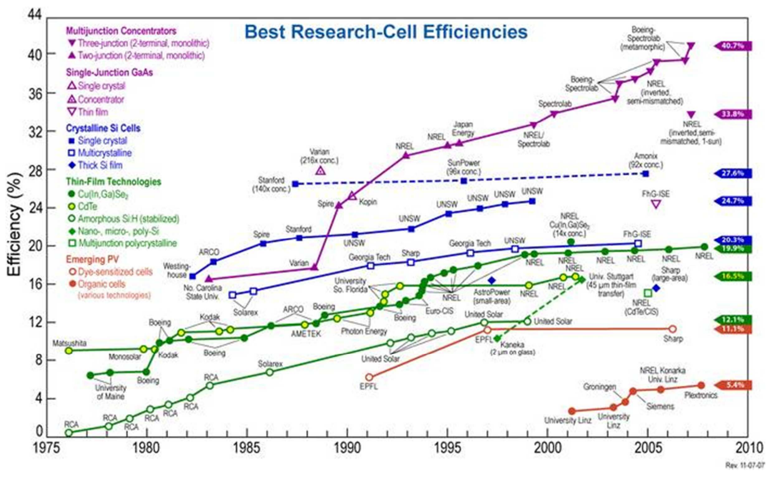

Figure 13: Best conversion efficiency of various types of experimental solar cells.

Without going into details we make the following interesting observations from the Figure:

- The efficiency of all types of solar cells has increased significantly over the past 35 years.
- Thin film solar cells, because of significantly very small quantity of material used for their fabrication, are the potential candidate for bringing down the cost of PV power generation. Therefore, it is perhaps the thin film solar cells which could emerge as the preferred devices for future power generation for terrestrial applications as against space and defense applications where a very high reliability is needs irrespective of the cost.

Despite very encouraging continuous gains in efficiency since 1975, and the cut down in the cost of materials, the overall cost of the PV devices for commercial power generation still remains highly uncompetitive.

4.7 Other Solar-PV Technologies

In addition to the ongoing research and development in conventional PV devices and technology summarized in Figure 13, research and development is also being undertaken in non-conventional materials and technologies to develop low cost PV devices and systems with a two-fold aim:

- Development of innovative technologies to bring down the cost of commercial production of devices, and
- Development of new and low cost materials.

Some non-conventional, low-cost solar cells initiatives, shown in Figure 14, are:

- Paint-on and spray-on solar cells (top row), [24].
- Carbon Nano-tube solar cells, (bottom left), [25].
- Large area, roll-on plastic solar cells [26].
- Hybrid solar cells [27],
- Pour-on printing of the grid on solar cells, (bottom right), [28].

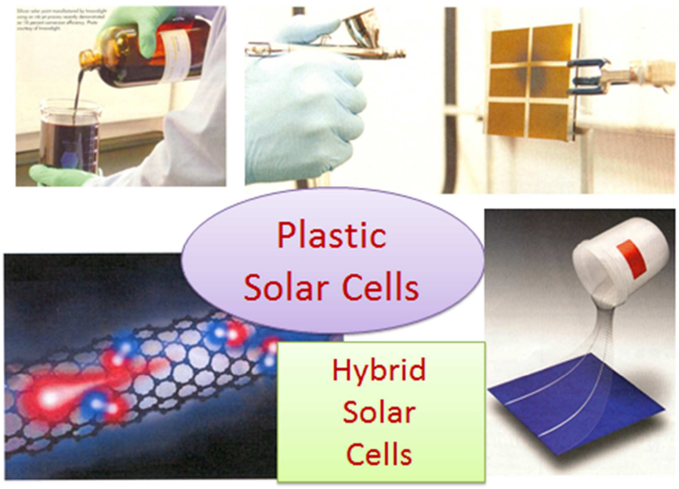

Figure 14: Examples of non-conventional materials and technologies used for the production of low-cost solar cells.

4.8 Renewable Energy Education and Training

It is not just the high cost that is responsible for low usage of solar energy devices and systems. In developing countries there are other limiting factors that are responsible for their low dissemination amongst which the prominent one is the shortage of trained manpower for their installation, repair and maintenance. Also, individual users and the procurement authority in case of institutional users often make wrong choices of devices and system because of the lack of information and understanding of the systems and devices. This results in frequent breakdowns and eventual failure of the devices leading to the loss of revenue as well as the consumer faith in the systems and devices. The Botswana story in this regard is no different. To overcome this barrier and to bridge the training gap, Energy Affairs Division (EAD), Government of Botswana had commissioned a nationwide consultancy on the renewable energy training programs needed in the country. The study was under taken by the author together with another colleague in the Faculty. The training programs recommended by the consultants are summarized in Figure 15 [29, 30]. These can be divided in to three categories:

- Courses to upgrade the skills of existing plumbers and electricians to NCC (National Craft Certificate) level in solar energy technologies and then to HND level (Higher National Diploma) in energy technologies.
- Training programs for the new intake of students starting at the C-certificate level and progressing all the way up to HND.
- Courses and short modules for students in secondary and tertiary education programs, managerial training for those involved in decision making for institutional procurement, user education, and public awareness programs.

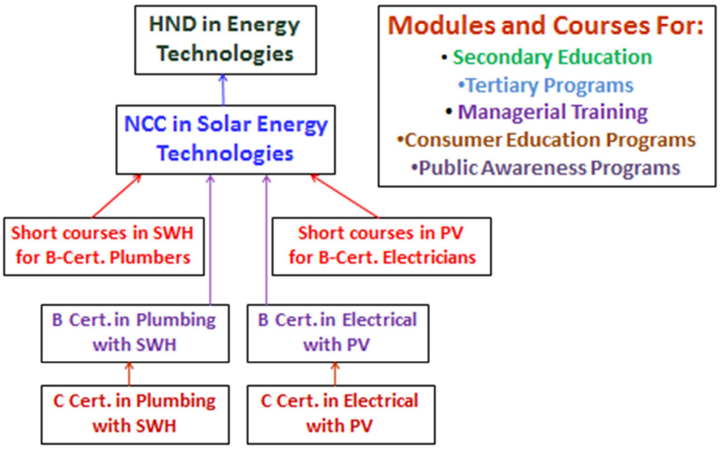

Figure 15: Recommended training programs in solar energy technologies for technical and managerial personnel.

4.9 Author's Contributions to Solar Energy Research prior to joining UB

Some of the solar energy research work undertaken by the author at the University of Botswana since 1987 formed the basis of the solar energy section of this lecture. Prior to joining the University of Botswana, the author had served for 7 years in India and for 4 years in Zambia where also his main research interest lay in solar energy and related areas. Because of space (time) limitation, it is not feasible to discuss those contributions and their significance here. However for completeness sake, author's contributions for the period 1976 to 1987 are listed below.

- Silicon single crystal growth for solar cell by CZ method, (National Physical Laboratory (NPL), Delhi, India: 1976 - 1978).
    - The technology was transferred to Poona Semiconductors Ltd., India and received share of the royalties, (unpublished: Industrial Research and Development).
- Growth of directionally frozen polycrystalline silicon for solar cells, (NPL, Delhi, India).
- Fabrication and testing of Si solar cells, (NPL, Delhi, India).
- Single axis, clock-work driven solar tracker, and a Fresnel lens design for solar concentration (Birla Institute of Technology and Science, Pilani, India: 1978 - 1982) [31, 32, 33, 34].

- The work on solar tracker was recognized by the Rolex Spirit of Enterprise Awards – 1981 [35].

- Theoretical studies of diffusion and purification mechanism in directionally frozen polycrystalline silicon for solar cells, (University of Zambia, Lusaka, Zambia: 1982 - 1986) [36].

5. ENERGY DEMAND, CONSUMPTION AND ECONOMIC DEVELOPMENT

Economic development is a complex process that depends on a wide range of factors, for example the availability and abundance of raw materials within the country and ability to extract them economically, access to raw materials in the global market economically, ability to value-added-processing of raw materials, ability to mass produce finished consumer and luxury products and appliances, ability to provide services that generate revenue or add quality to life or both, access to global markets for the domestic products and services, competitiveness of products and services in the global market etc. Peace and stability, low corruption and crime rates, good governance, and government policies also play key role in development. However in an oversimplified model, economic development can be attributed to scientific and technological development leading to industrial development and revenue generation opportunities. This in turn results in growth in energy demand and consumption. Thus energy demand and consumption can be taken as fair indicators of economic development of a society. Our focus on economic development in this lecture, therefore, is projected in terms of access to abundant energy sources to fuel it.

5.1 Growth in Global Energy Demand

Growth in energy demand is governed by three factors: population growth, industrial growth, and growth in household energy consumption in industrialized societies where people lead energy intensive luxurious life style with high standards of living. In recent decades energy efficiency and conservation initiatives have also impacted noticeably on the energy demand. Figure 16 [37] shows world energy consumption and the world population from 1850 to 2000.

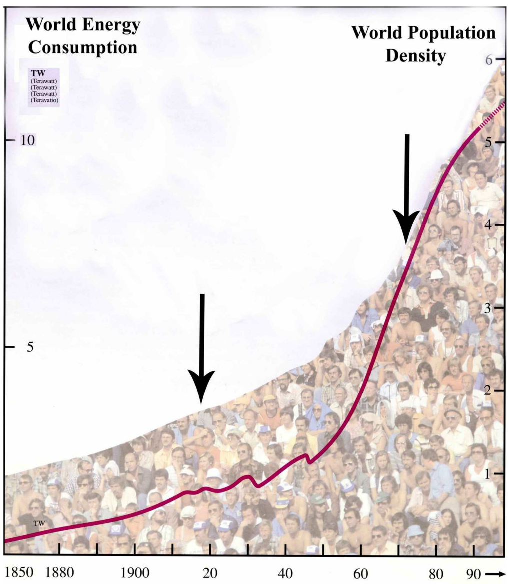

Figure 16: Growth in world energy consumption and the world population from 1850 to 2000.

A trivial observation from the figure is that the increase in energy demand is linked to growth in population. But with a careful observation infused with the basic knowledge of the pattern of development of human society during this period, much more interesting observations can be made. For this purpose we have divided the figure into three periods as indicated by the vertical arrows. We observe:

- Up to early 1900, the growth in energy demand and the growth in population are nearly linearly related. During this period the use of energy was limited to the basic needs of cooking, heating and lighting. With nonexistence of motorized transport, and almost no-motorized industry, the linear relationship is not only obvious but rightly justified.
- From 1900 to 1970s the demand in energy grew at a much faster rate than the growth in population. This is the period of rapid industrialization and fast growth in motorized land, air and marine transport. During this period the living standards of people in industrialized societies also improved with corresponding increase in domestic energy consumption.
- From mid-1970s the energy demand grew at a slower rate than the population growth. This resulted from greater efforts towards energy conservation and improved energy efficiency following the oil crisis of 1972.

5.2 World Energy Consumption

It is well known that the industrialize countries not only consume significantly much more energy than the less developed countries, there is also a vast disparity in the quality of energy used by the two. In this sub-section we analyze the rate of per capita energy consumption, sector wise energy consumption, and the energy mix which tell the story of the status of development for different regions and countries of the world.

From Figure 17 [38] we note that the developed countries of the world with only 21% of the world population consume 60% of the world energy. In contrast to this, the developing countries having 79% of the world population consume only 40% of the world energy. Thus the average per capita energy consumption of developed countries is nearly 5.6 times that of developing countries.

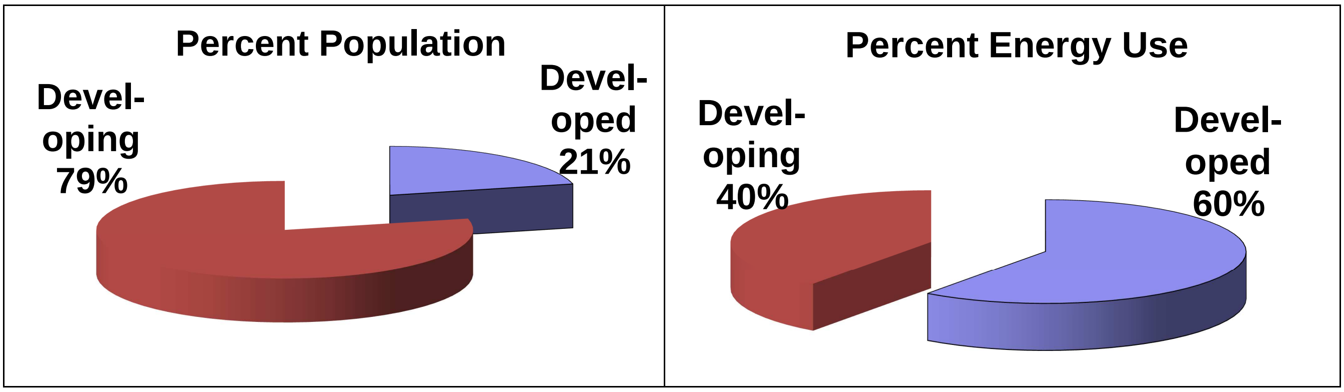

Figure 17: 21% of the world population in developed countries consumes 60% of the world energy resources.

The same observation is emphasized differently in Figure 18 which shows per capita energy consumption against per capita GDP in US$ for some of the countries of the world. From the figure we arrive at similar conclusions as earlier, i.e.:

- Highly industrialized countries of the world like the USA have a very high per capita GDP and correspondingly these countries have very high per capita energy consumption. These countries lie in the upper right corner of the figure.
- The developing and less developed countries for example most countries of Africa lie in the lower left corner of the figure. These countries have very low per capita GDP and their per capita energy consumption is also very low.
- The center area of the figure is populated by countries with medium per capita GDP and medium per capita energy consumption.

In general, there is a direct relationship between per capita GDP and per capita energy consumption. High energy consumption points to high level of industrialization which in turn means more income generating opportunities. With more income at the disposal of consumers, they can afford better lifestyle leading to more domestic energy consumption to support luxury lifestyle. Just the opposite is true in the case of less developed countries.

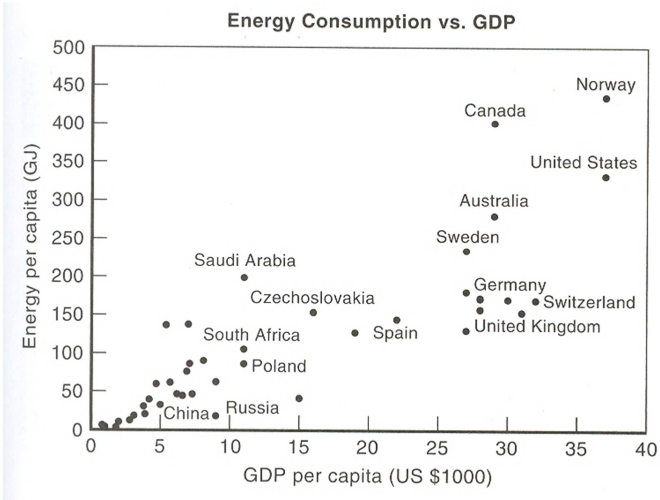

Figure 18: Per capita energy consumption of a country is directly related to its per capita GDP.

Similar disparity is displayed by the rate of consumption of the total energy, and the rates of consumption various forms of energy sources by different regions of the world. These are shown in Figures 19 to 23 (Data for the graphs are taken from online resources: [38]).

Figure 19 shows per capita total energy consumption for various parts of the world, represented by 5 groups of bar charts. These are the world; some regions of the world (Group 1); developed and developing group of countries (Group 2); high, middle and low income countries (Group 3), and lastly Botswana. The chart clearly shows high to very high rate of energy consumption by the developed countries and the high income countries, and low energy consumption rate is recorded for the developing, and middle and low income countries. Starting from this to the next four figures, I would like the readers (audience) to keep their attention focused on the bar charts for the high, middle and low income countries (Group 3) and Botswana.

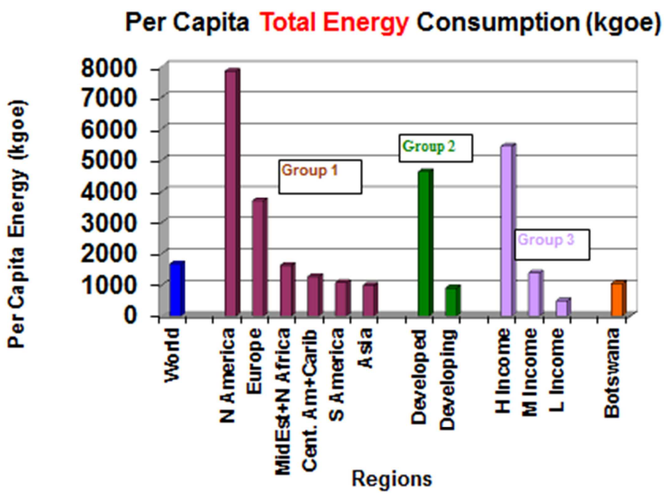

Figure 19: Per capita total energy consumption (kgoe) for select regions/ group of countries.

Figure (20) shows per capita residential energy consumption, Figure (21) shows per capita electricity consumption, Figure (22) shows per capita petrol consumption, and Figure (23) shows per capita diesel consumption for the same regions of the world and the same groups of countries as in Figure (19).

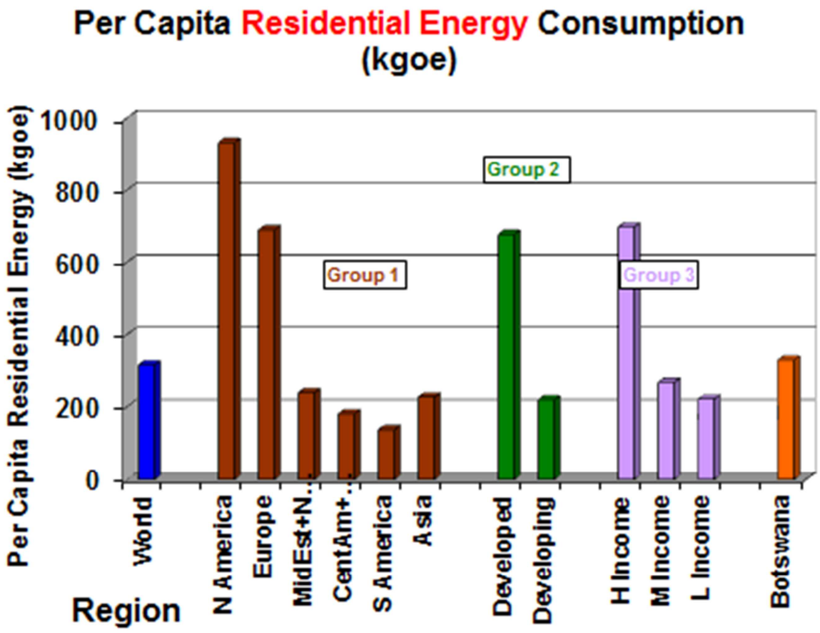

Figure 20: Per capita residential energy consumption (kgoe) for select regions/ group of countries.

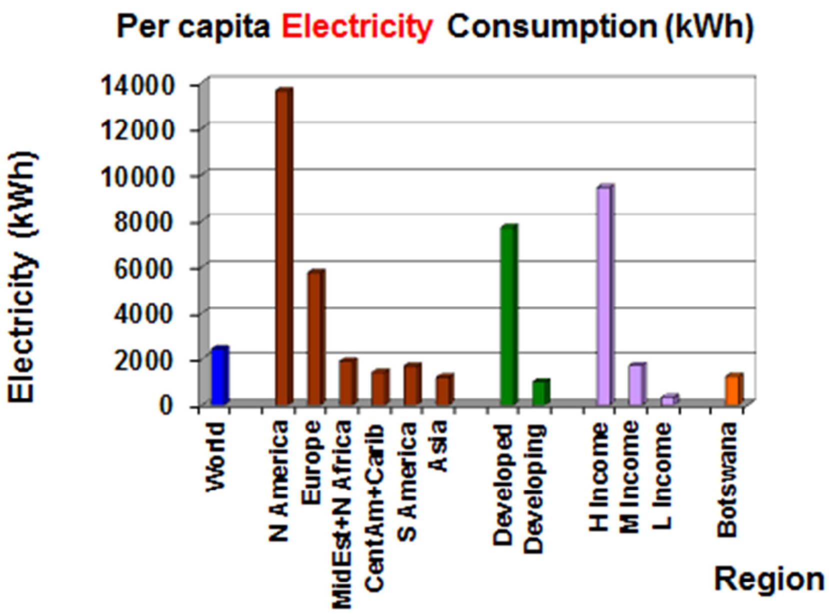

Figure 21: Per capita electricity consumption (kWh) for select regions/ group of countries.

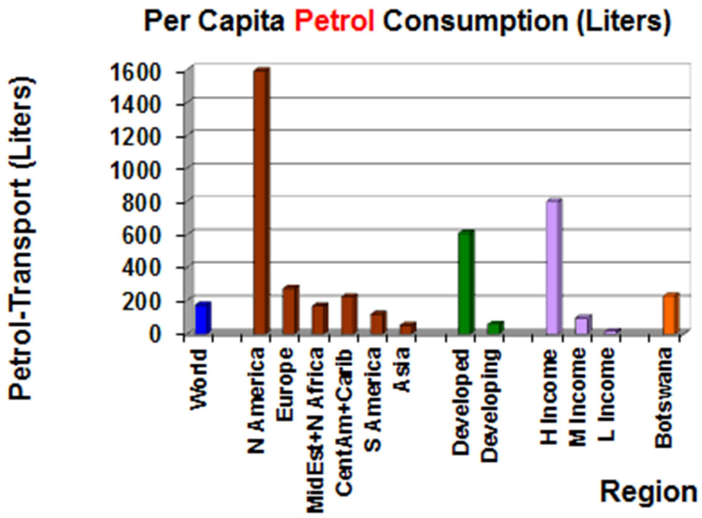

Figure 22: Per capita petrol consumption (liters) for select regions/ group of countries.

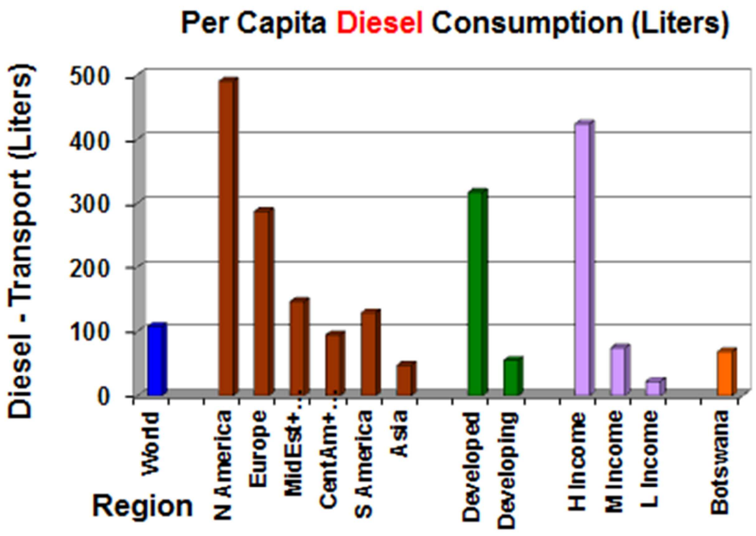

Figure 23: Per capita diesel consumption (liters) for select regions/ group of countries.

Interestingly all the charts from Figure 19 to 23 display identical patterns of energy consumption. But more interesting is the observation that per capita consumption for Botswana in all the five Figures mimics middle income countries as we also know from the economic data of the world. Thus, from the analysis of energy consumption pattern one can fairly accurately assess the economic status of a country even though one need not have knowledge of and expertise in the field of the world economy.

5.3 Primary Energy Mix

An important aspect of energy use is the contribution of various sources of energy to the total energy supply, termed as *Primary Energy Mix.* This is shown in Figure 24 [38] as percentages of the total energy supply for some of the regions of the world. From the Figure we note that the developing countries, for example the countries of Africa, rely heavily of wood fuel, a low grade source of energy. Over 40% of total energy in Africa is supplied from wood fuel, whereas wood fuel contributes only about 3% of total energy in North America. In North America largest source of energy used is oil which is a high grade commercial source. In Botswana wood contributes about 30% of total energy. This once again confirms middle income, developing country status of Botswana. The *"other"* source of energy in case of Botswana represents imported electricity mainly from South Africa which is about 12% of the total primary energy supply.

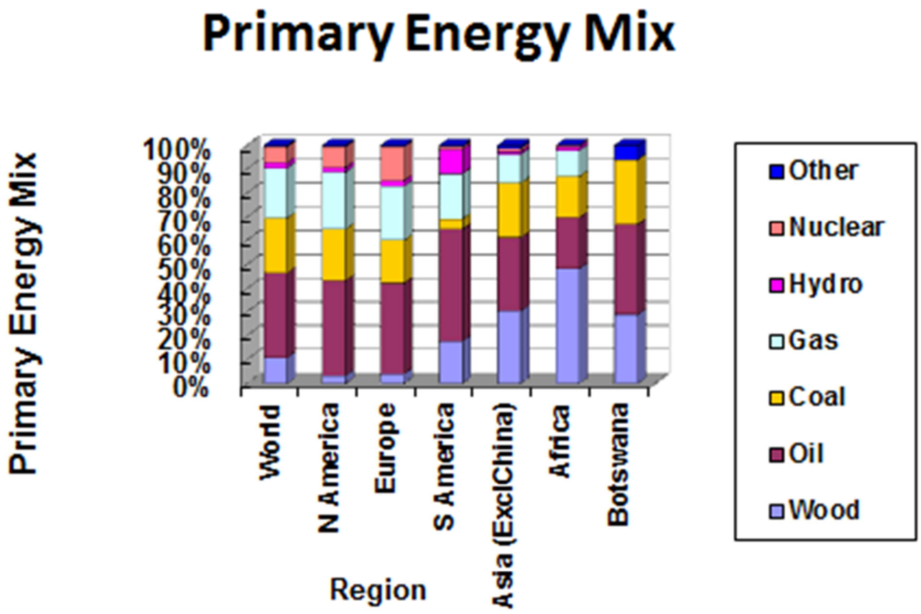

Figure 24: Primary energy mix for select regions/ group of countries.

5.4 Sector-wise Energy Use

Sector-wise energy usage as percentage of the total energy consumption (Figure 25 [38]) is an indicator of the level of the industrial and commercial development of a country and the level of the standard of living of its people. In developing countries a large fraction of energy is used by the residential sector for the basic need of cooking, lighting and heating, whereas in developed countries the industrial and the transport sectors are the largest consumers of energy. This scenario is highlighted by Sub-Saharan Africa where the total energy consumption itself being very low, most of the energy is used by the residential sector and only a very small fraction is consumed by the industrial and the transport sectors. This shows that both these sectors, the industry as well as the transport, are not well developed in Sub Saharan Africa. Here one point is to be noted carefully: a large fraction of energy being used by the residential sector in Sub-Saharan Africa does by no means mean that their standard of living is very high. This must be considered together with the primary energy mix as well as the total energy consumption. Firstly, in Sub-Saharan Africa most of the energy is supplied by wood fuel which is used by the domestic sector for cooking and heating. Secondly, a large fraction of significantly smaller total energy consumption by the domestic sector translates to a very small energy use by the domestic sector.

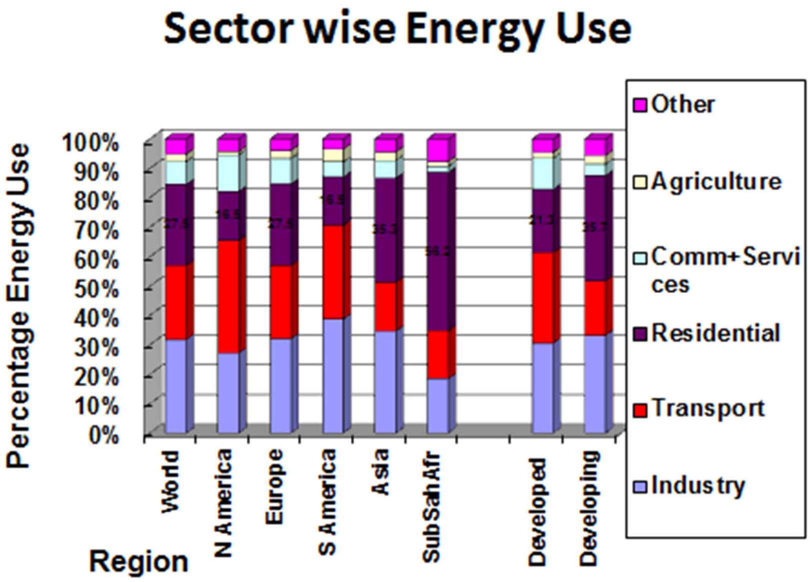

Figure 25: Sector wise energy use for select regions/ group of countries.

5.5 Energy Intensity

Energy intensity determines how effectively and efficiently the energy is used. It is defined as the energy used to generate one unit of GDP in products and services. Essentially energy intensity is the *"Economic Efficiency"* of energy use. Different sectors of the economy namely industry, agriculture, transport and service sectors have different energy intensities. The service sector generally should have a low energy intensity, whereas an energy intensive industry such as metallurgical industry shall have a high energy intensity. Old, less energy efficient machines or inefficient workforce would result in higher energy intensity than normally expected. Therefore, energy intensity audit of a sector is an important exercise to ensure most efficient use of energy and committed and able workforce. It is not always necessary that lower energy intensity means the best case scenario. In some cases it is the higher energy intensity that points to better performance of the sector. For example in the agriculture sector, subsistence farming, where non-motorized machines are used, would have very low energy intensity but it would involve a large workforce to produce food for the country. Thus, subsistence farming is labour intensive and the output is low. However, mechanized, commercial farming has high energy intensity involves less workforce and the yield is much higher. Commercial farming also frees the workforce from agriculture to participate in industrial development. Thus, even though commercial farming has high energy intensity, it is the most desirable way of food production to feed the masses in an industrialized world.

Figure 26 [38] shows overall energy intensity of some of the regions of the world for 1990, 2000, and 2003. From the figure we can make some interesting observation about the *"Energy – usage - health"* of the overall economy of these regions without going into finer details of the individual sectors. We observe:

- Overall energy intensity across the world has improved over the period from 1990 to 2003. This is the result of energy conservation and improved energy efficiency initiatives.
- Low income countries have the worst energy intensity whereas the high income countries use the least amount of energy to generate the same amount of GDP.
- Sub-Saharan Africa is the worst case scenario where extremely large amount of energy is consumed to produce every US$ worth of products and services. This could be due to a number of limiting factors, for example the use of old and less fuel efficient machines and vehicles, and deployment of less skilled or less committed work force etc.

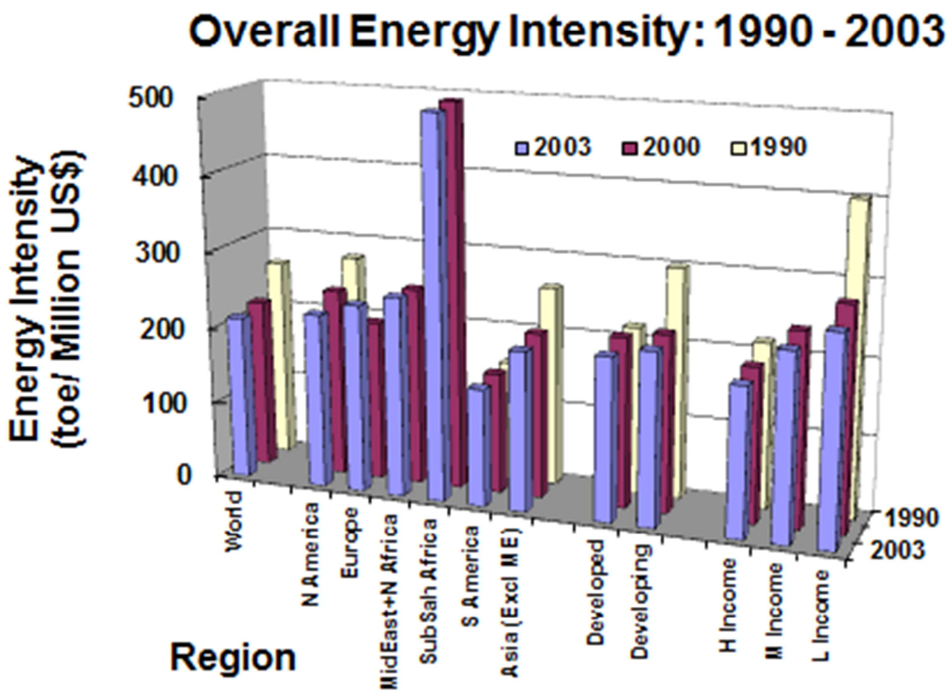

Figure 26: Overall energy intensity for select regions/ group of countries for 1990, 2000 and 2003

5.6 Energy Supply and Use in Botswana

Having discussed the world energy demand, supply and consumption at length, it is appropriate that we conclude this section with a brief insight into the energy scenario in Botswana. This is a vast topic in itself warranting a full length lecture. In view of the space and time limitation, we restrict ourselves to some salient features of the energy sector in Botswana as follows.

- Botswana is an importer of 100% of refined oil products from South Africa.
- Botswana holds vast coal reserves.
- Over 75% of electricity consumed in the country is imported from the neighbouring countries. The Republic of South Africa supplies over 90% of the imported electricity.
- Locally produced coal is used for local electricity generation.
- Energy distribution and transmission infrastructures are underdeveloped. Nearly 40% of the total population in remote rural areas have no or limited access to electricity and oil products. Wood fuel is the main source of energy for remote and rural population.
- Wood-fuel contributes over 35% to the total energy consumption.
- Renewable energy contributes less than 1% to the total energy supply although Botswana is endowed with excellent solar conditions. Another untapped source of renewable energy is the cattle dung in a country with cattle population nearly twice the human population. The wind energy potential is very little.

The flow chart in Figure 27 [39] shows energy supply by sources and their use in Botswana.

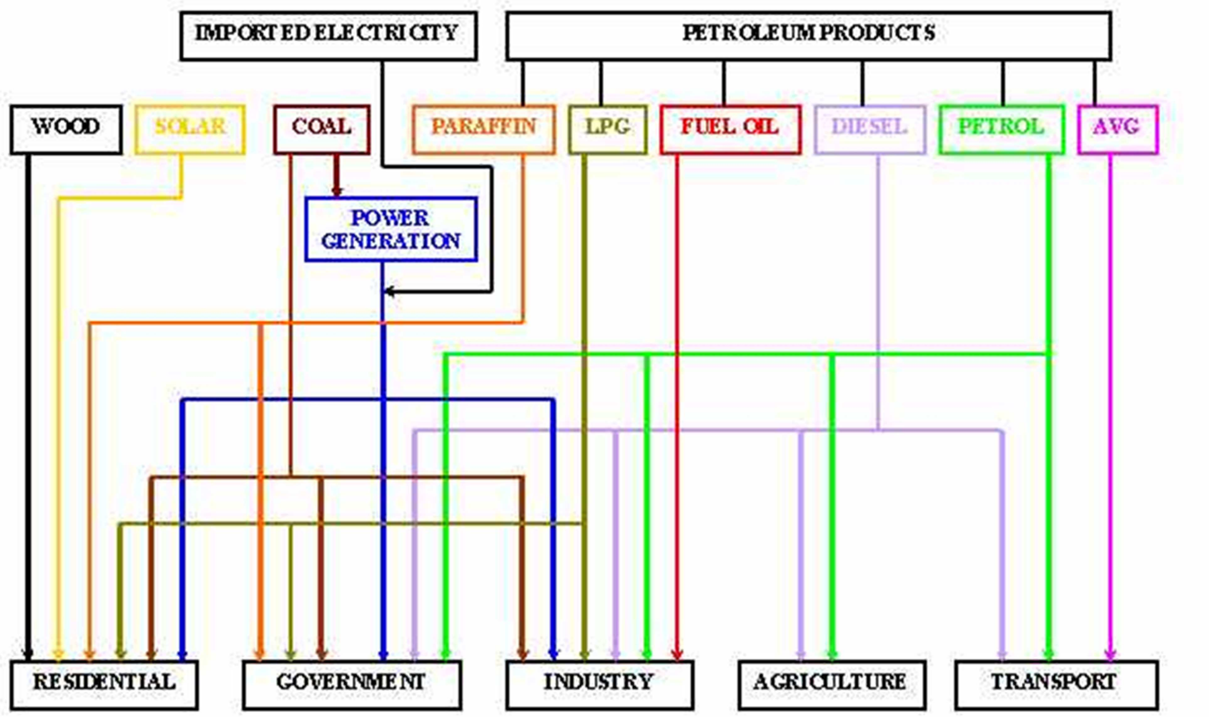

Figure 27: Energy supply and use in Botswana

6. ENVIRONMENTAL IMPACT OF ENERGY USE

At present 80% of the world energy is supplied by fossil fuels and 10% by biomass. Their production, distribution and combustion leads to the degradation of our atmosphere, land and water bodies. Once again, degradation of the environment from energy use is too vast a topic to be presented here in fair detail. We highlight only some basic facts about the environmental impact of energy use for completeness sake.

- Atmospheric pollution results mainly from the combustion of fuels which adds to the atmosphere:
    - Greenhouse gases (GHG): About 68% of GHG are energy generated. These include:
        - Carbon dioxide
        - Carbon monoxide
        - Oxides of nitrogen
        - Methane.
    - Non-GHG emissions include:
        - Oxides of sulfur
        - Lead and mercury
    - Particulate and volatile matter, namely:
        - Suspended particles
        - Volatile organic compounds.
- Energy generated water pollution includes:
    - Acid rain: In some towns in China acid rain is so severe that the bus stop signs have to be changed every few years because of their corrosion by the acid rain.
    - Pollution of oceans results from fuel leakage from ships, spillage from oil tankers, marine accidents, and off-shore drilling.
    - Pollution of surface and ground water.

- Land degradation from energy use is seen in the form of:
    - Deforestation.
    - Desertification.
    - Leaching of soil from acid rain.
    - Disposal of waste generated from the energy production, distribution and use.
- Radioactive pollution: This is the most hazardous form of pollution with long lasting damage to our environment. It is caused from accidents in the nuclear power plants for example the Chernobyl accident of 1986, and from the byproducts and the waste produced by the nuclear industry.

Figure 28 shows some examples of air, land and water degradation. It is not uncommon to see heavily smoking vehicles such as the one shown in the lower left corner of the Figure on the roads in Botswana.

Figure 28: Examples of environmental degradation from energy production, distribution and use.

7. ENERGY INDICATORS OF DEVELOPMENT

Having discussed at length the world energy demand, supply and consumption in relation to development we can now identify the following *"Energy Indicators of Development"*.

- Social and cultural development of a society leads to increased energy consumption.
- Growth in population as well as industrial development results in increased energy demand.
- To support industrial growth more commercial energy sources are needed and the infrastructure for their distribution must be expanded.
- Affluent societies consume more energy from commercial sources to support their luxury life style.
- Usage of large quantity of traditional energy sources indicates that a large proportion of the population is underdeveloped living in remote and rural areas with an underdeveloped and inadequate infrastructure for the production and distribution of commercial energy sources.
- Demographic shift from rural to urban population results in greater demand for energy and the demand shifts from traditional to commercial energy sources.
- Energy intensity shows how efficiently the energy is deployed in various sectors of the economy, and how successful are the energy conservation and efficiency initiatives.
- Increased consumption of fossil fuels leads to increased environmental degradation. Appropriate measures must be put in place to minimize their use and to maximize environmental protection while sustaining development.

8. ENERGY SECURITY AND SUSTAINABILITY

At present the world energy consumption comprises 17% electricity, 44% low temperature heat, 10% high temperature industrial heat and 29% transport fuels. There is a very large disparity in total energy consumption amongst the countries of the world. A major proportion of the total world energy (over 75%) is used by the developed countries, whereas the developing and underdeveloped countries are hard hit by energy poverty. About 2 billion people worldwide have no access to energy services and another 2 billion have inadequate and unreliable energy services. All these people live in developing countries. As developing countries embark on development, their energy demand shall grow at a faster rate than that of the developed countries and most of the demand should be supplied from the commercial energy sources. Figure 29 [40] shows four scenarios of energy demand up to 2100 for various combinations of assumptions, namely: Rate of population and industrial growth, Technological development, Resource availability, and pressure from the Environmental concerns.

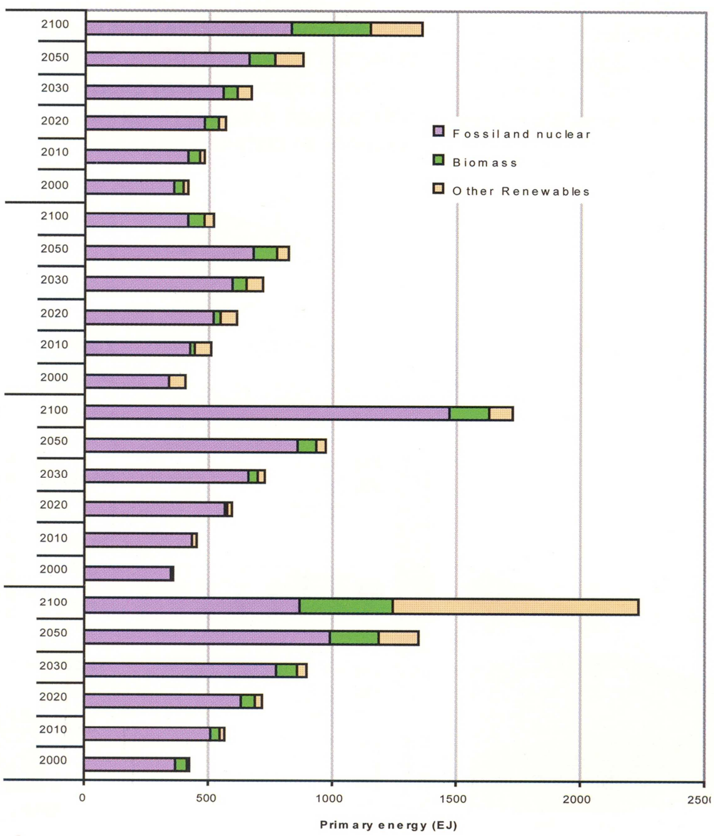

Figure 29: Projected world energy demand to year 2100 for four different growth and development scenarios.

From the Figure we make the following obvious observations:

- The energy demand shall continue to grow, albeit at different rates for different growth scenarios.
- Fossil fuels shall continue to play an important role in the world primary energy mix.
- The contribution of renewable energy sources and technologies shall also grow.

Considering these factors, all the countries will have to meet the increasing demand of energy with a mix of sources that may not be available within their borders as is the case even now. This could not only threaten the energy security of the developing countries but also of the developed ones. Under these circumstances one cannot talk of self-sufficiency in energy, rather energy security and sustainability are the guiding factors. Which of the new sources and technologies shall provide a large share of future energy demand shall differ from country to country and from region to region. This is best summarized in the following statement:

> *"No single solution can meet our Society's future energy needs. The answer lies instead in a family of diverse energy technologies… that share the common thread. They do not deplete our resources or destroy our environment".* --- The Union of Concerned Scientists, USA

8.1 Possible Threats to Energy Security

Some common threats to energy security include:

- Political instability and conflict in regions where major energy sources: oil, gas and coal are concentrated.
- Use of energy as a weapon of negotiation by the producers.
- Use of energy as a weapon of war and to deploy military might to secure energy supply.
- Natural calamities affecting energy production and supply.
- Break down in energy production and supply chain.
- Inadequate investment in energy production and distribution sectors by producers and distributors.
- Terrorism targeting energy production and supply sector.
- Market volatility.

In order to counter these threats and to attain energy security and sustainability, countries must:

- Increase domestic production and rely as much as possible on indigenous sources to minimize energy import.
- Diversify energy mix so as not to depend heavily on any one source.
- As per the IEA (International Energy Agency) recommendation and guideline, hold reserves of imports equivalent to 90 days consumption in the previous year. In case of disruption of 7% or more in supply, share reserves with IEA member states.
- Strong regional cooperation in energy must be forged through trade treaties and infrastructure linkages.
- Energy conservation and efficiency must be continually improved to make that last drop go an extra mile.

Since fossil fuels shall continue to dominate the energy scenario for the foreseeable future, their prices are bound to soar with increasing demand and depleting reserves. In order to arrest the runaway cost of energy it is becoming more pertinent now than ever that:

- Oil reserves which were uneconomic to mine shall become economically viable and shall be opened.
- Will have to go deeper, farther, and to more remote locations in search of new reserves.
- Less used unconventional sources like peat, tar, tight sands and shale shall have to be exploited fully.

Figure 30: With depleting resources and increasing demand, the future of fossil fuel driven economy could look like this in not too distant a future.

If we do not act wisely locally while thinking globally now, our only possible mode of transport, for example, could be expected to be like the one shown in Figure 30 in not too distant a future.

In conclusion, energy is a very complex multi-disciplinary field, like a 3-D jig-saw puzzle (Figure 31 [41]). In this presentation, we could have a glimpse of only a few pieces of the puzzle that revealed only a tiny bit of a corner of the larger picture. A large many pieces of the puzzle remain hidden from the view. It is hoped that whatever little justice we could do to such a vast topic in this lecture will inspire our audience and readers to fathom the *vast ocean of energy* at their own pace out of interest and curiosity.

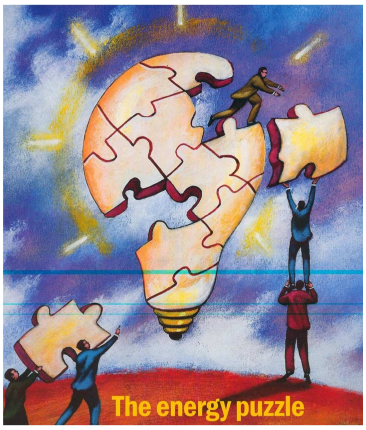

Figure 31: Energy issues are a 3-D complex jig-saw puzzle.

Acknowledgements:

■ **Variety of help and support** from the following are acknowledged with sincere thanks and gratitude:
• University of Botswana: Faculty of Science, Extramural and Public Education Department - Center of Continuing Education, UB Administration, Support and Maintenance staff, Colleagues in the Department of Physics, • Research collaborators, • Students, • Mr. Stephan Coetzee, • Community friends and families, • My family: Wife - Prof. Priti Jain, Daughters - Gauri, and Shilpi, Son - Shitesh and Son-in-law - Brendon.

■ **Photo Credits:** • GTZ GmbH, Germany, • Energy Affairs Division, Botswana, • Botswana Power Corporation, • International Energy Agency, • Sun World magazine, • Physics World magazine • Internet resources,

■ **Data Credits:** • Energy Affairs Division, Botswana, • Botswana Department of Meteorological Services, • Department of Agricultural Research, Botswana, • International Energy Agency, • Internet resources.

References:

1. World Commission on Environment and Development, *Our Common Future*, Oxford University Press, Oxford, (1987).
2. Cleveland, J C and Morris, C (Editors), *Dictionary of Energy,* Elsevier Ltd., London, UK, (2006).
3. Jain, P K and Nkoma, J S, *Introduction to Mechanics: Kinematics, Newtonian and Lagrangian,* Bay Publishing (Pty) Ltd., Gaborone, Botswana, (2004).
4. *Control of fire by early humans.* Online: Wikipedia - the free encyclopaedia, http://en.wikippedia.org/wiki/Discovery_of_fire
5. *Millennium Development Goals.* Online: Wikipedia - the free encyclopedia, http://en.wikipedia.org/wiki/Millennium_Development_Goals
6. *Botswana Vision 2016: Towards Prosperity for All*. Online resource: http://www.vision2016.co.bw
7. *Key world energy statistics* – 2009, International Energy Agency, Paris.
8. Skinrood, A C, R*ecent developments in central receiver systems,* Sunworld, **6** (4), 99 – 101, (August 1982).
9. *Themis (solar power plant).* Online: Wikipedia - the free encyclopedia, http://en.wikipedia.org/wiki/Themis_(solar_power_plant)
10. *Solar Power Tower.* Online: Wikipedia - the free encyclopedia*,* http://en.wikipedia.org/wiki/Solar_power_tower
11. *List of solar thermal power stations.* Online: Wikipedia - the free encyclopedia, http://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations
12. Jain, P K, *Passive solar architecture: Improved thermal comfort at little or no additional cost,* Proceedings (CD ROM) of the joint CASLE and Afres International Conference on Sustainable Human Settlements for Economic and Social Development, Livingston, Zambia, 169-180, (May 2007).
13. Jain, P K, Davis, G L and Hunt, G, *Thermal comfort analysis of common house types* in *Botswana* in Renewable Energy, Energy Efficiency and the Environment, Vol III, 1456 – 1459, Pergamon, UK, (1996).
14. Jain, P K and Bingana, L, *Low-cost passive solar housing in Botswana: Effect of design parameters on indoor temperatures* in Renewable Energy, Energy Efficiency and the Environment, Vol III, 1441 – 1445, Pergamon, UK, (1996).
15. Nijegorodov, N, Devan, K R S, Jain, P K and Carlson, S, *Atmospheric transmittance models, and an analytical method to predict the optimum slope of an absorber plate, variously oriented at any latitude,* Intl. J of Renewable Energy, **4**, 529 – 543, (1994).
16. Jain, P K and Lungu, E M, *Harmonic analysis of solar radiation data for Sebele, Botswana* in Renewable Energy: Renewables – The Energy for the 21st Century, Part IV, 2575 -2578, Pergamon, UK, (2000).
17. Jain, P K, Lungu, E M and Prakash, J, *Bivariate models: relationship between solar irradiation and either sunshine duration or extremum temperatures,* Intl. J of Renewable Energy, **28,** 1211 – 1223, (2003).
18. Jain, P K, Prakash, J and Lungu, EM, *Correlation between temperature and solar irradiation in Botswana: Bivariate model,* Proceedings of the 2nd IASTED Africa Conference – Modelling and Simulation (Africa MS 2008), 170 – 174, (Paper 603-048) (2008). Also online on the IASTED website: http://www.actapress.com/Abstract.aspx?paperid=34064
19. Jain, P K and Lungu, E M, *Stochastic models for sunshine duration and solar irradiation,* Intl. J of Renewable Energy, **27,** 197 – 209, (2002).

20. Jain, P K, Prakash, J and Lungu, E M, *Climatic characteristics of Botswana.* Proceedings of the IASTED International Conference on Modelling, Simulation and Optimization (IASTED: MOS – 2006), 96 – 105, (Paper 507-110), (2006).
21. Loster, Matthias, *Total primary energy supply: Required land area.* Online resource: http://www.ez2c.de/ml/solar_land_area/
22. International Energy Agency, *Renewables for Power Generation: Status and Prospects,* (IEA/ OECD), p 20, (2003).
23. (a): National Renewable Energy Laboratory (NREL), USA, *Timeline of solar cell energy conversion efficiencies* , from Online resource: http://en.wikipedia.org/wiki/Solar_cell , in the Telgu language at: http://te.wikipedia.org/wiki/%E0%B0%B8%E0%B1%8C%E0%B0%B0_%E0%B0%98%E0%B0%9F%E0%B0%82
    (b): Online Google image gallery: Image web-link http://www.google.co.bw/url?sa=i&source=images&cd=&cad=rja&uact=8&docid=wV_4Kk_FQhM1oM&tbnid=Sfi1zgn9J8zTBM:&ved=0CAgQjRw&url=http%3A%2F%2Fte.wikipedia.org%2Fwiki%2F%25E0%25B0%25B8%25E0%25B1%258C%25E0%25B0%25B0_%25E0%25B0%2598%25E0%25B0%259F%25E0%25B0%2582&ei=ckKxU-bQOY-r0gWcwICgCg&psig=AFQjCNFyza-Wkb9BiRWN0kZBbgf3VVJQGA&ust=1404212211033734
    (c): Kurtz S., *Opportunities and Challenges for Development of a Mature Concentrating Photovoltaic Power Industry*, Technical Report of NREL/TP-520-43208, Revised November 2009, http://www.dfrsolutions.com/uploads/newsletter%20links/2010-03/CPV_Opportunities%20and%20Chall enges_SKurtz.pdf
24. Fischer, Anne L., *Painting the roof with solar ink,* Green Light Section in Photonics Spectra, November 2009, p. 28.
25. Ju, Anne, *Carbon nanotubes could make efficient solar cells,* Cornell Chronicle Online, September 10, 2009. http://www.cornell.edu
26. Freebody, Marie, *A closer look at plastic solar cells,* Photonics Spectra, October 2009, p. 45.
27. Fischer, Anne L., *Peering into a hybrid solar cell,* Green Light Section in Photonics Spectra, December 2009, p. 29.
28. Fischer, Anne L., *Nonactive solar materials make a difference,* Green Light Section in Photonics Spectra, December 2009, p. 28 - 29.
29. Jain, P K and Lungu, EM, *Study to assess new and renewable sources of energy (NRSE) training in technical schools in Botswana – Final Report,* Energy Affairs Division, Ministry of Minerals, Energy and Water Affairs, Government of Botswana, (Tender No: 10/ 1/ 2/ 96-97), (1997).
30. Jain, P K, Lungu, E M and Mogotsi, B, *Renewable energy education in Botswana: Needs, Status, and Proposed training programs,* Int. J of Renewable Energy, **25**, 115 – 129, (2002).
31. Jain, P K, Gupta, K C, Sathe, A P and Borania, C H, *A Clockwork driven one-axis tracking system*, Proc. National Solar Energy Convention – 1979 (NSEC-79), IIT Bombay, India, Paper 22, pp 114 – 117, (1979).
32. Jain, P K, Somadev, Y, Gupta, K C and Sathe, A P, *Alignment and performance of a single-axis solar tracking system,* Proc. National Solar Energy Convention – 1982 (NSEC-82), IISc, Bangalore, India, Paper CH:04, pp 2.010 – 2.013 (1982).
33. Jain, P K, *A clock driven, cost-efficient solar tracker,* Sun World, **6**, 176 – 180, (1982).

34. Jain, P K, Gupta, R, Gupta, K C and Sathe A P, *A novel profile of a Fresnel lens for solar energy application,* Proc. National Solar Energy Convention – 1982 (NSEC-82), IISc, Bangalore, India, Paper CH:05, pp 2.014 – 2.016 (1982).
35. Jain, P K, *A simple cost-efficient solar tracker* in the Rolex Awards Book – 1981: *"Spirit of Enterprise – The 1981 Rolex Awards"* pp 106 – 107, Editor: Gregory B Stone, Publisher: W H Freeman and Co., USA. (Rolex Awards-1981 Ref No: A01016; Category: Applied Science and Invention).
36. Jain, P K, *Preparation of low-cost, solar-grade polycrystalline silicon,* Proc. AUP International Workshop on Physics and Technology of Solar Energy Conversion, pp 76 – 96, Editor: O Awe, University of Ibadan, Nigeria, (1985).
37. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, German Federal Ministry for Economic Cooperation and Development (BMZ). Adapted from the: *1994 wall calendar* on the theme: *"Energy • Change • Future".*
38. World Resources Institute, Washington DC, USA: Online various energy databases at: http://earthtrends.wri.org/text/energy-resources/variable-351.html
39. Jain, P K, Leipego, A, Kerekang, K, Mathangwane, F and Molosiwa, K, *Energy,* Chapter 11 in the "Botswana National Atlas", First Edition, pp 149 – 156. Published by the Department of Surveys and Mapping, Ministry of Local Government, Lands and Housing, Government of Botswana, (2001).
40. *Current and possible future contributions from renewable energy* in "Changing Climates: The role of renewable energy in a carbon-constrained world" a Renewable Energy Policy Network for the 21st Century (REN21) report, pp 8 – 13, United Nations Environment Programme (UNEP), (2006).
41. Cover page, *Physics World,* **22,** (10: October), Institute of Physics, UK, (2009).