UNIVERSITY OF BOTSWANA

Sustainable Development: Energy Matters

Inaugural Lecture
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Sustainability:

"Human endeavour which meets the needs of the current generation without jeopardising the needs of future generations."

In the context of energy this can be stated as:

"Energy that is produced and used in ways that will support long-term human development in all its social, economic, and environmental dimensions."

Development:

"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 outcomes of development.*
- Though the benefits are not necessarily evenly distributed throughout the population.

Energy Matters has dual meaning**:**

- ***The issues relating to energy, and***
- ***Energy plays a role.***

Putting both parts together the title alludes to:

Energy issues and the role of energy in sustainable development

OUTLINE

- Energy and Development
- Global Energy Demand
- Energy Resources
- Solar Energy
- World Energy Consumption
- Environmental Degradation and Energy Use
- Energy Indicators of Development
- Energy Security and Sustainability

1. Energy and Development

- *"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 the others"*

  -Eugene Odum, US Physicist (2001)

❖*Social, cultural and technological development*

❖*Economic development*

1.1. Social, Cultural, and Technological Development

- Life prior to the discovery of fire.
- Discovery of fire.
- Animal power.
- Invention of the wheel.
- Wind and tidal power.
- Use of coal and invention of the steam engine.
- Liquid fuels and invention of the internal combustion engine.
- Power generation and electrical machines.

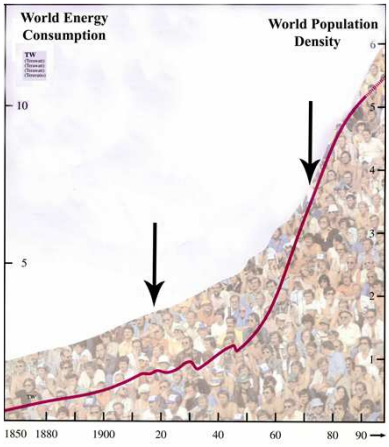
- Third Industrial Revolution.
- Development of new and renewable sources of energy:
  - Solar, wind, tidal, geothermal, nuclear…,
- Access to "Right" energy → Prerequisite to all development initiatives:
  - Millennium Development Goals (MDG - 2015)
  - Vision 2016: Toward Prosperity for all. For example:
    - Child and mother mortality, and life-saving health services.
    - Eradication of poverty, and hunger, universal primary education.

1.2. Economic Development

… an outcome of scientific, and technological development leading to industrial development and revenue generation which are fuelled by sources of abundant energy.
For example:

- Extraction and value added processing of raw materials.
- Production of finished products.
- Mass production of consumer and luxury goods.
- Provision of services that generate revenue or add quality to life or both.

2. Growth in Global Energy Demand

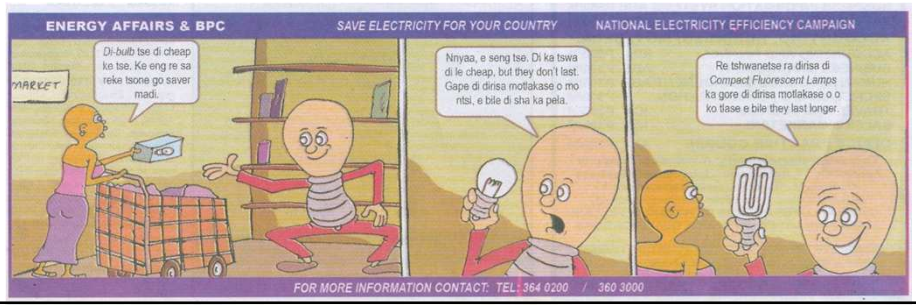


- Basically, energy demand increases with increase in population.
- Up to early 1900s growths in population and energy demand are nearly linearly related.
- From 1900s to 1970s energy demand grew at a faster rate than the population.
- From 1970s the energy demand grew slower than the population.
- With growing demand of energy, new sources of energy are developed to meet the demand.

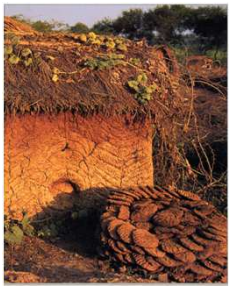
3. Energy Resources

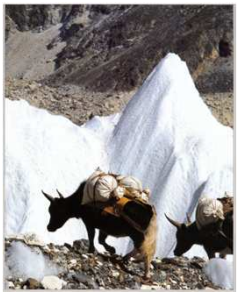
- **Classification Scheme 1:**
  - Traditional or Low grade energy resources
  - Commercial or High grade energy resources

- **Classification Scheme 2:**
  - Non-renewable sources of energy
  - Renewable sources of energy



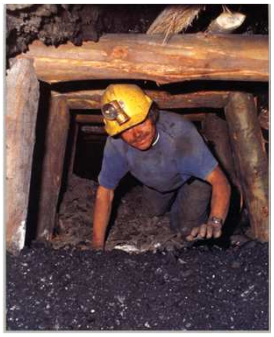
3.1. Traditional energy sources

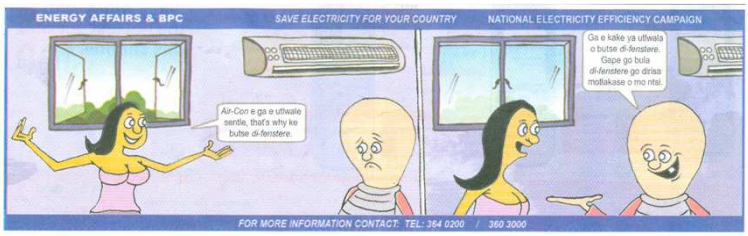






3.2. Fossil fuels

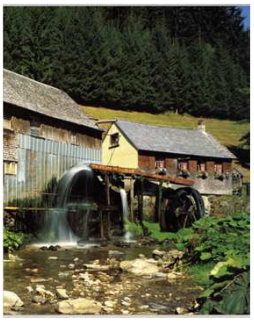
(Non-renewable, Commercial)





Solar **Tidal** **Bio-fuel**

Geothermal **Biogas** **Wind**



Water wheel

Mini-hydro

Large hydro-power plant

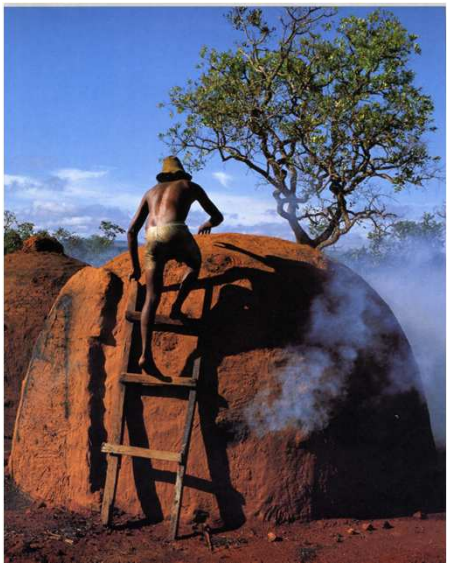
3.4. Fuel Conversion

(Man made, Renewable/Non-renewable)

Coal
Oil
Gas
Nuclear
Hydro
Solar
Wind
Geothermal
Tidal
….

→

→



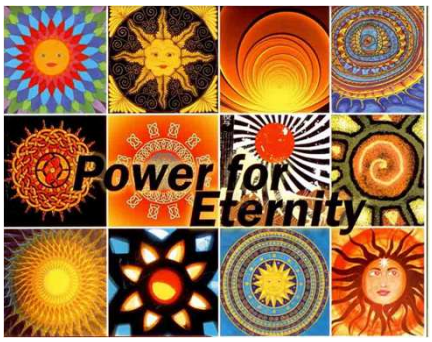
3.5. Other Energy Sources and Technologies

- **In use , some with large applications:**
  - Nuclear fission
  - Peat, Tight and Tar sands, Shale
  - Waste dump gas…
- **In limited use or in R & D stage:**
  - Nuclear fusion (advanced R&D)
  - Hydrogen
  - Fuel cells
  - Combined Heat and Power (CPH)
  - MHD generator …

SOLAR →

- **Solar has the largest potential and is the most relevant to Botswana.**
- **It is already in limited use in Botswana for:**
  - Lighting
  - Space and water heating
  - Refrigeration
  - Water pumping
  - Telecommunication
  - Broadcasting
  - Village electrification
- **This is the area of energy research to which I have contributed.**

4. Solar Energy

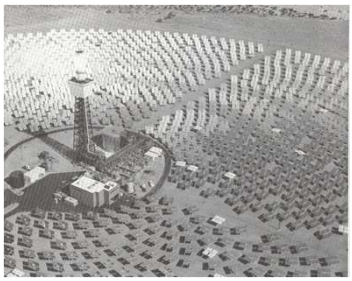


- **Solar Technologies:**
  - Solar Thermal.
  - Solar Photovoltaic.
- **Solar Devices:**
  - Non-Concentrating
    - Fixed installation.
  - Concentrating
    - Up to 5-Sun: Single axis tracking.
    - More than five sun: Double axis tracking.

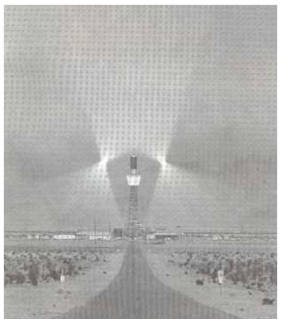
4.1. Central Receiver Systems (Power Towers)

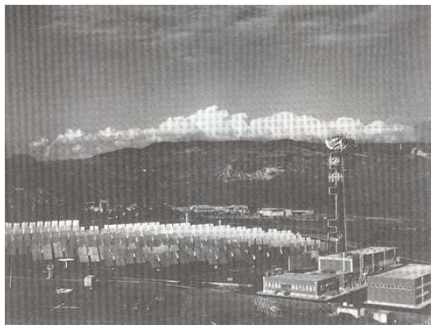
- Produce extremely high temperature heat.
- Heat is used to generate power or for metallurgy.
- Large number of large-area plane mirrors in a field of several square kilometer area reflect solar radiation on to a central receiver.
- Each plane mirror (heliostat) continuously tracks the sun to maintain focus on the receiver.
- CRSs of capacity 10MWe have been in use in many countries.

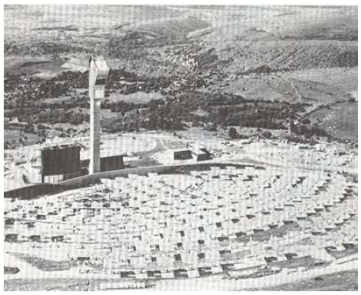
10MW Power Tower, Barstow, California, USA.

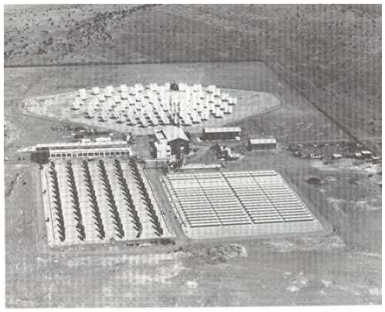
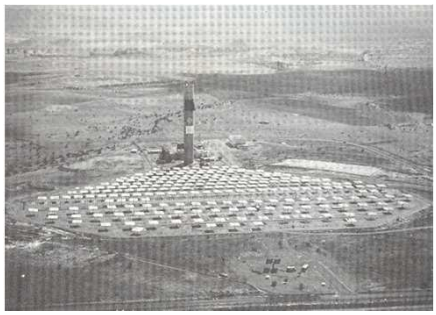
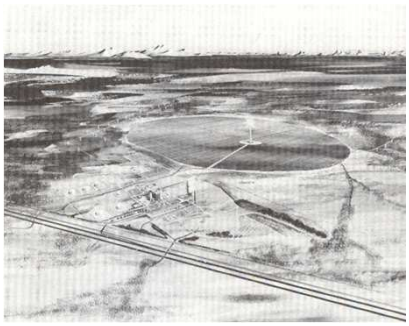
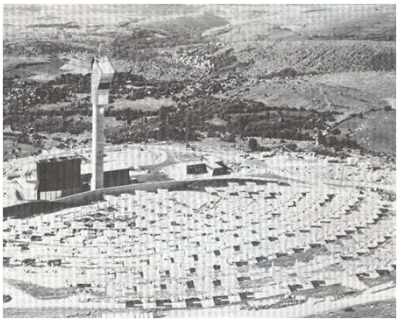


- Capacity 10 MW.
- It has 1818 heliostats.
- Each heliostat: 39.3 sq. m.
- Tower height is 80 m.
- Heat is stored in:
  - 6798 tons of rock + Heat transfer oil .
- Plant can run at 7 MW power for up to 4 hr. from the stored heat.



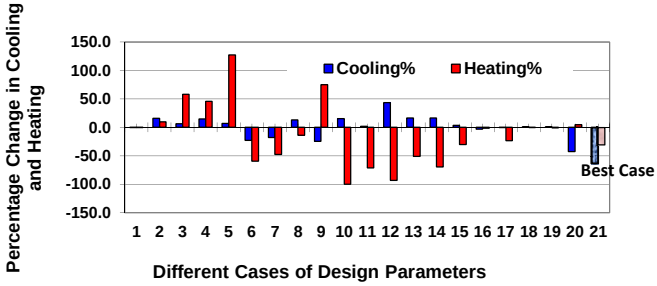




4.2. Passive solar architecture

- Optimum use of solar energy is made for natural lighting and for improved indoor thermal comfort by:
  - controlled direct solar gain,
  - selective absorption of solar energy, and
  - controlled release of absorbed energy.
- Some design considerations are: Building orientation; window area and placement; exterior surface colour; choice of building materials.
- Result is: Improved indoor thermal comfort without the use of A/C devices and natural day-lighting with no or a small extra cost of construction → Overall saving in energy.
- Buildings have been constructed in Botswana , for example the BOTEC Headquarters in Gaborone.

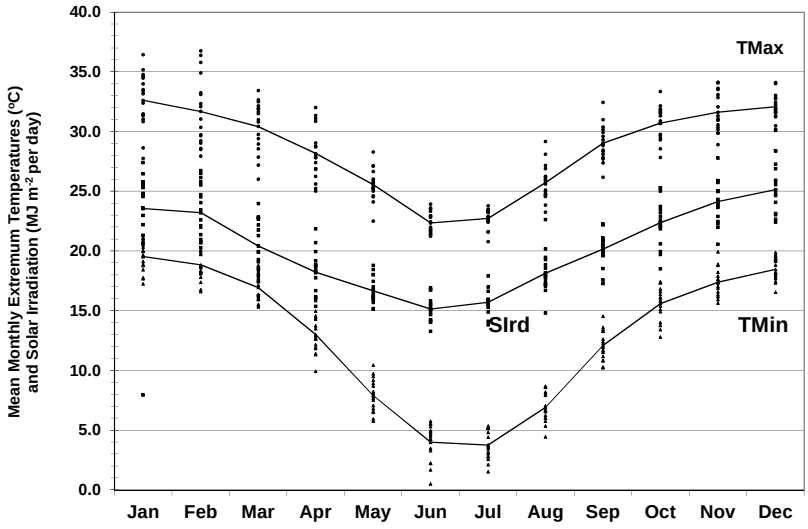


Best Case Scenario:

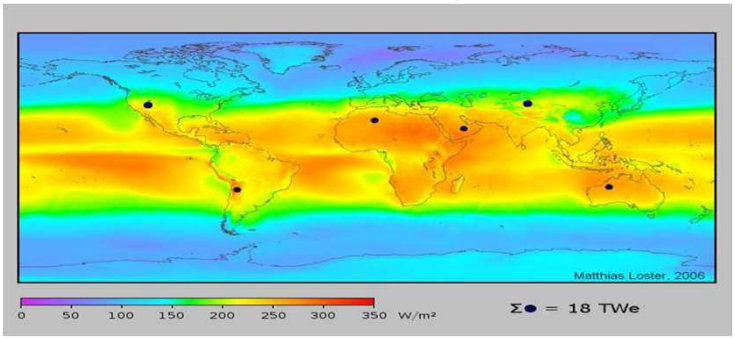
- 60% energy saving in winter heating load.
- 30% energy saving in summer cooling load.
- Vastly improved indoor temperatures without the use of space conditioning (*not shown here*).

4.3. Solar Radiation Simulation

- Solar radiation data is essential for sizing of solar systems 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.
- Solar radiation modeling for Botswana has been done by myself and collaborators within the FoS. Modeling techniques developed are available in published literature. These include:
  - Atmospheric transmittance models.
  - Monovariate ARIMA models.
  - Bivariate models correlating extremum temperatures and solar radiation, and sunshine duration and solar radiation.
- Measured data shown in the next slide is the basis for the extremum temperatures and solar radiation models.

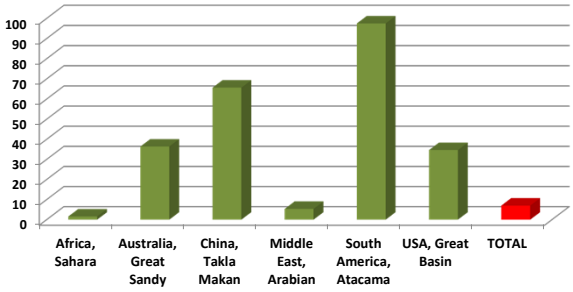


4.4. Global solar potential

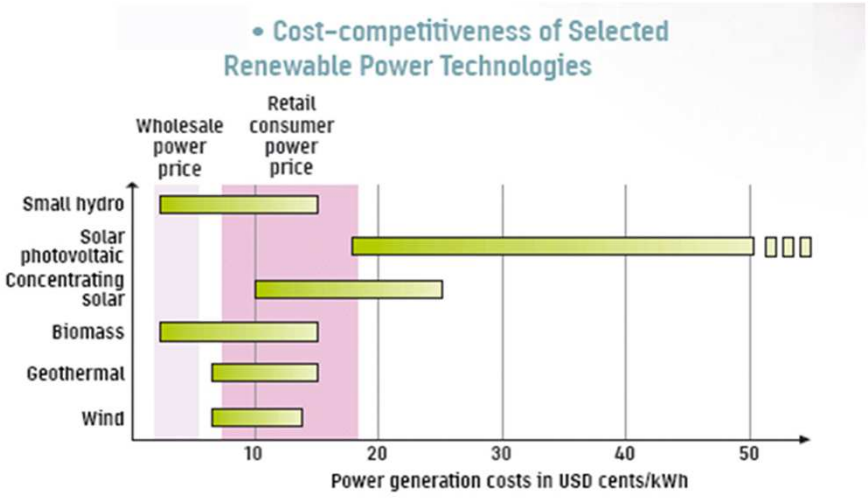


8% efficient PV devices covering 7% of total desert area at six locations in the figure → will produce 13,567 Mtoe electricity → more than the total world energy consumption in 2006 (11,741 Mtoe)

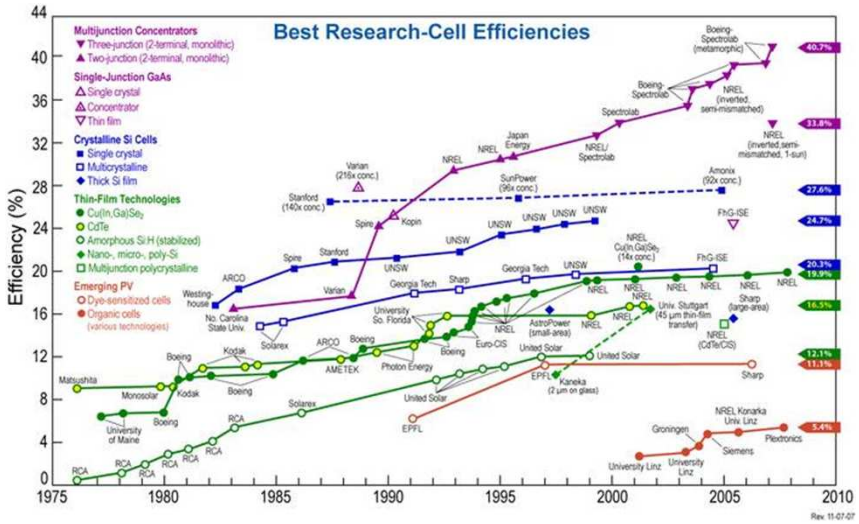
Location/ Desert	Desert Area (km^2)	Area Covered (km^2)	% Covered
Africa/ Sahara	9,064,960	144,231	1.6
Australia/ Central Sandy	388,500	141,509	36.4
China/ Takla Makan	271,950	178,571	65.7
Middle East/ Arabian	2,589,910,	138,889	5.4
S. America/ Atacama	139,860	136,364	97.5
USA/ Great Basin	492,100	170,455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

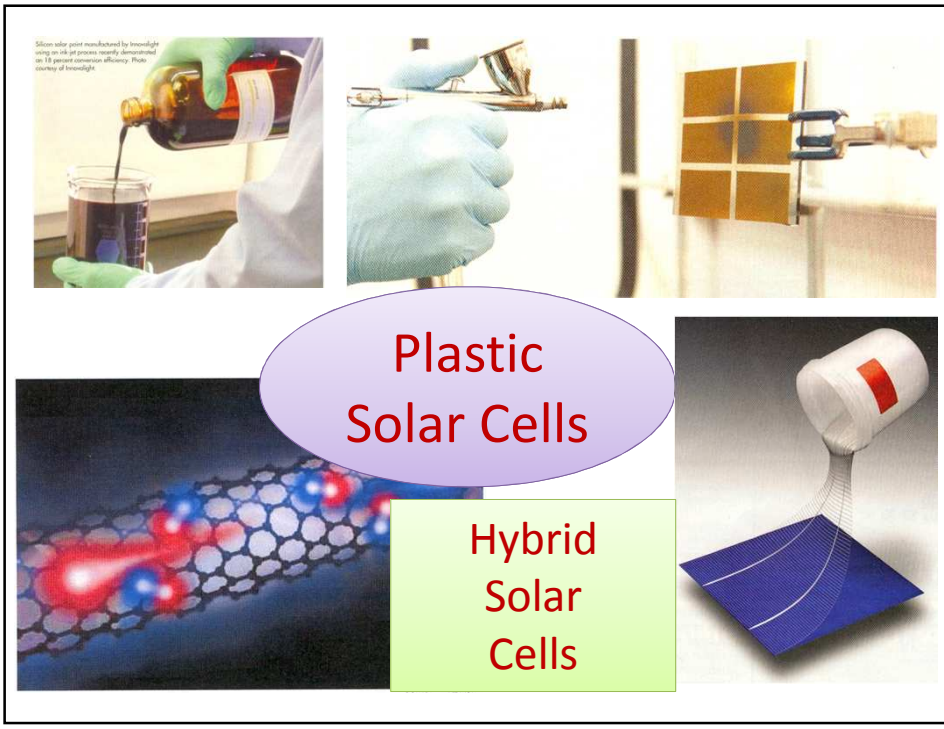


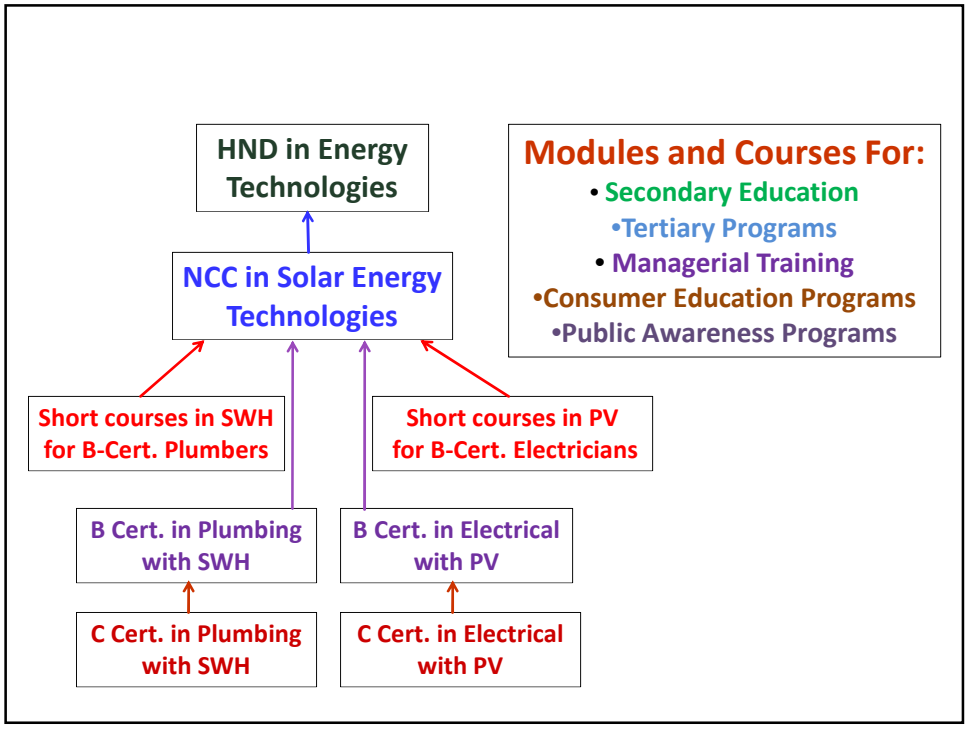
4.5. Comparative Cost of RE-Power Generation



4.6. Conversion efficiency of PV devices







4.9. Solar energy research before joining UB

•Silicon single crystal growth for solar cells by CZ method, *(NPL, Delhi)*.

- Technology was transferred to Poona Semiconductors Ltd. and received royalties.

• Growth of directionally frozen polycrystalline silicon for solar cells, *(NPL, Delhi)*.

•Fabrication and testing of Si solar cells, *(NPL, Delhi).*

•Single axis, clock-work, solar tracker *(BITS, Pilani).*

- Work recognized by Rolex Spirit of Enterprise Awards – 1981.

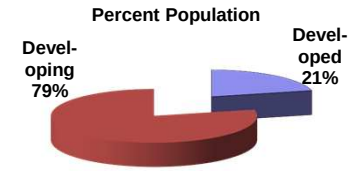
•Theoretical studies of diffusion and purification mechanisms in directionally frozen polycrystalline silicon for solar cells, *(UNZA, Lusaka).*

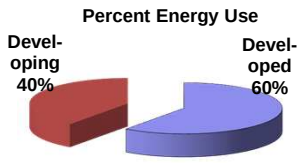
5. World Energy Consumption

•Variations in total and per capita energy consumption, energy mix, sector wise energy usage, and energy intensity are analyzed.

•Industrialized countries consume significantly more energy than the less developed and developing countries.

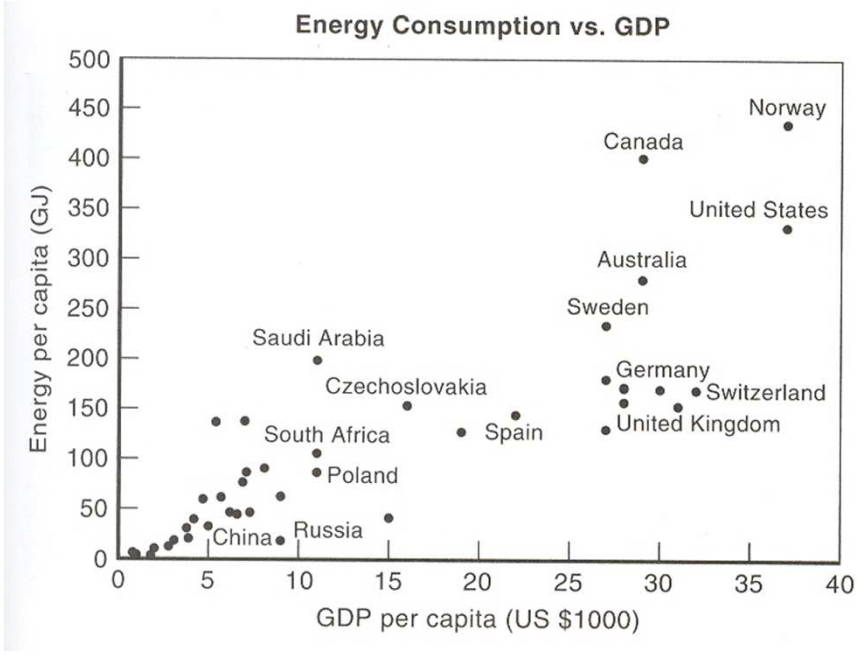
→

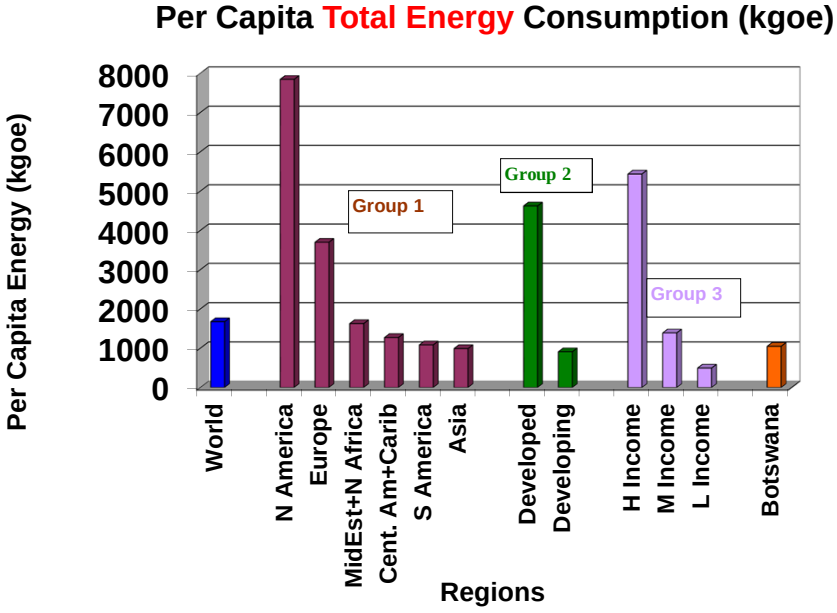


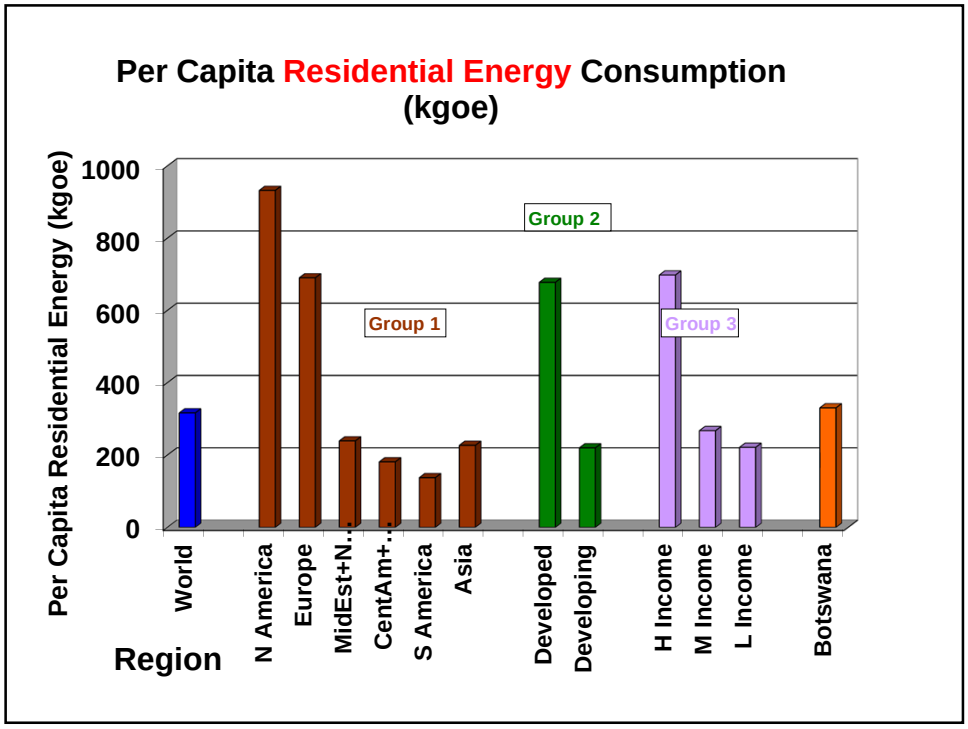


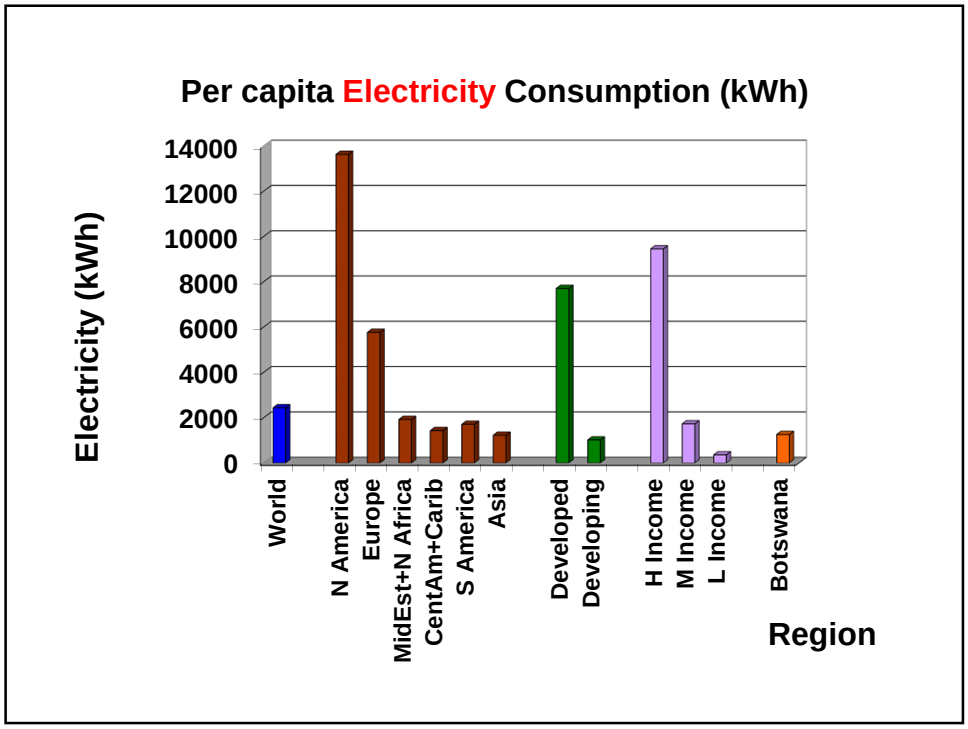
•Developed countries with 21% of the world population consume 60% of world energy.

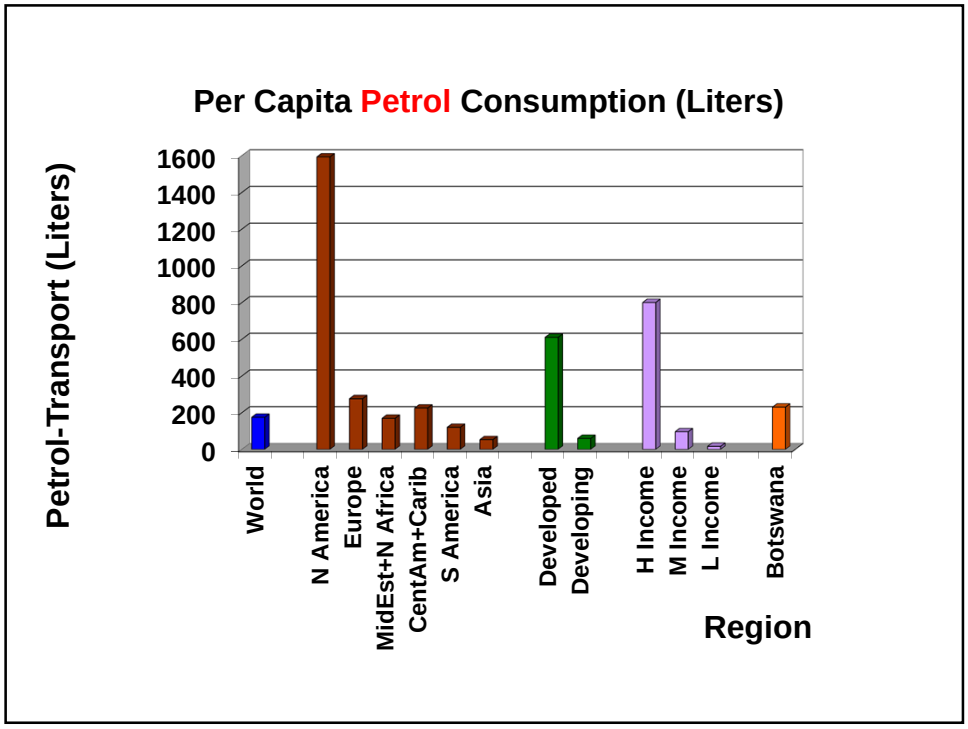
•Developing countries with 79% of world population consume only 40% of world energy.

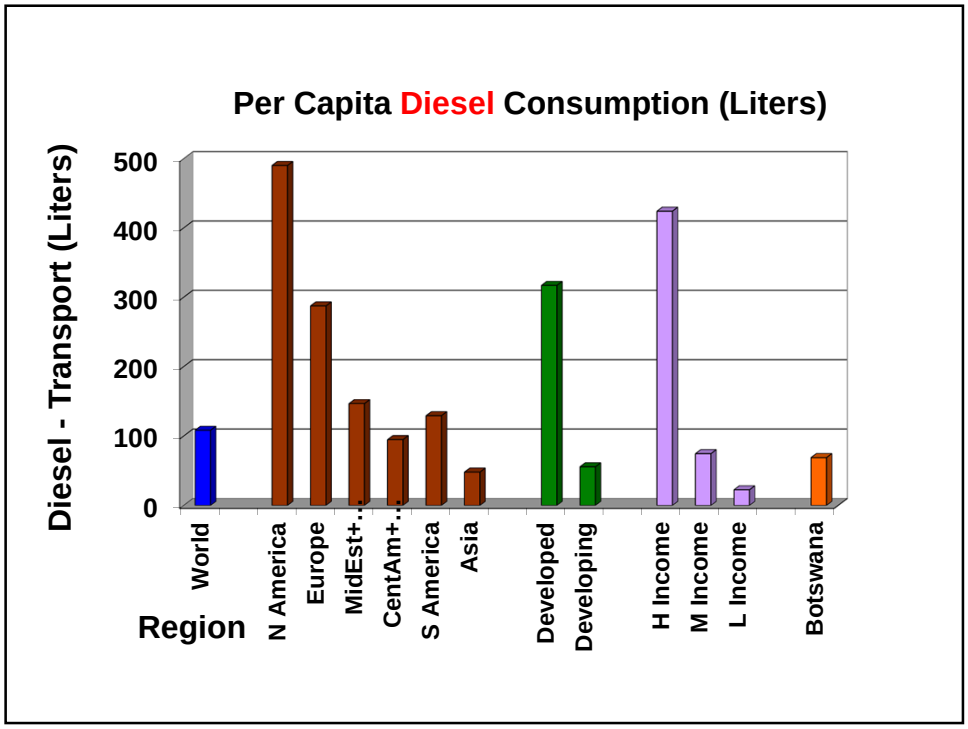

Energy Consumption vs. GDP
Energy per capita (GJ)
GDP per capita (US $1000)
Norway
Canada
United States
Australia
Sweden
Saudi Arabia
Germany
Switzerland
Czechoslovakia
United Kingdom
South Africa
Spain
Poland
China
Russia
0
50
100
150
200
250
300
350
400
450
500
0
5
10
15
20
25
30
35
40

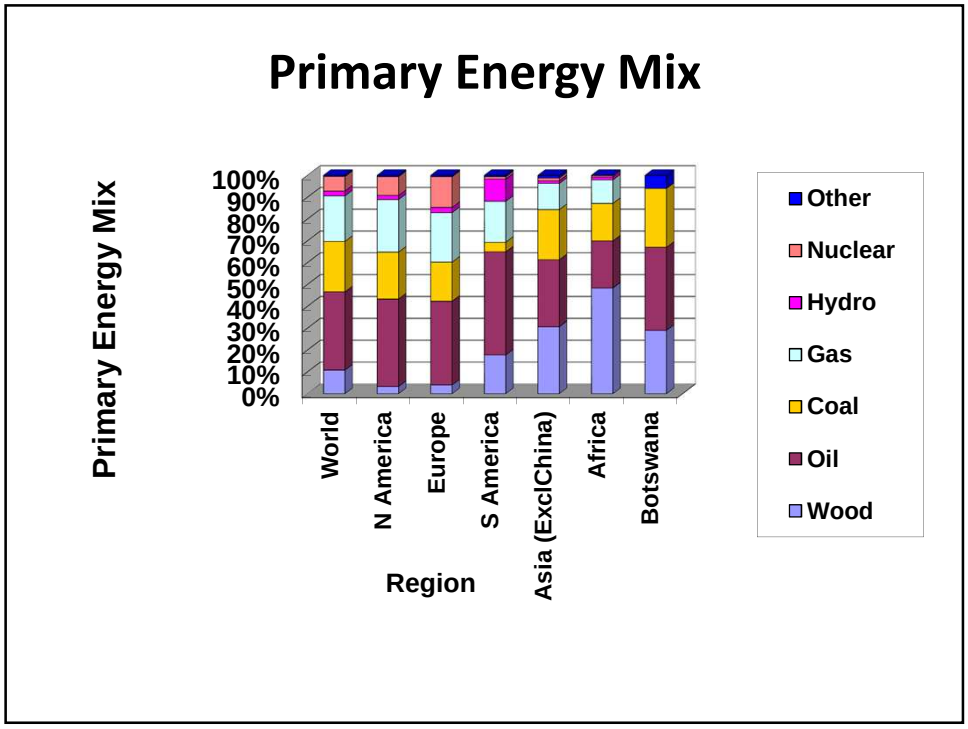

Per Capita Total Energy Consumption (kgoe)
Per Capita Energy (kgoe)
8000
7000
6000
5000
4000
3000
2000
1000
0
Group 1
Group 2
Group 3
World
N America
Europe
MidEst+N Africa
Cent. Am+Carib
S America
Asia
Developed
Developing
H Income
M Income
L Income
Botswana
Regions

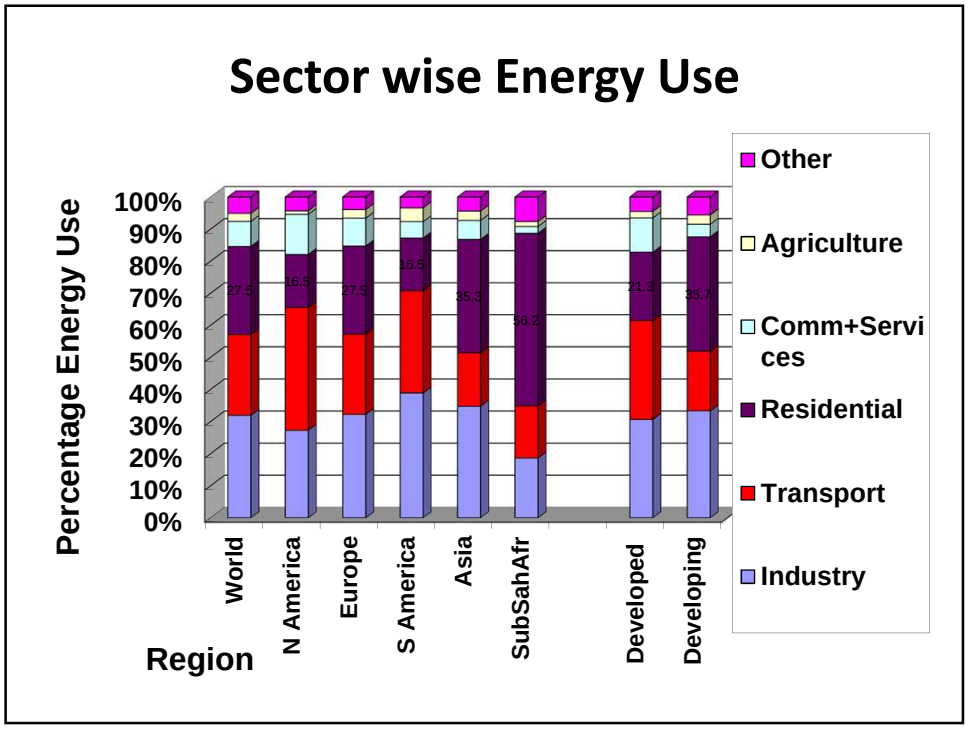

Per Capita Residential Energy Consumption (kgoe)
Per Capita Residential Energy (kgoe)
1000
800
600
400
200
0
Group 1
Group 2
Group 3
World
N America
Europe
MidEst+N..
CentAm+..
S America
Asia
Developed
Developing
H Income
M Income
L Income
Botswana
Region

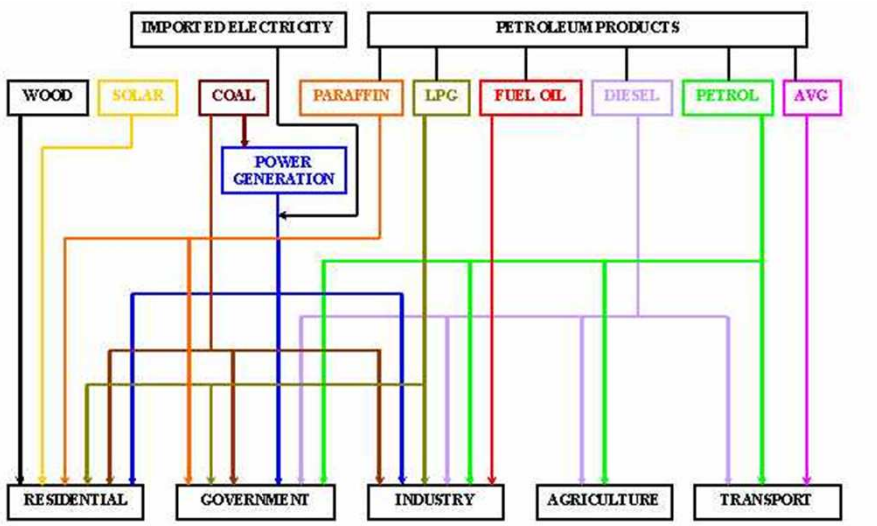

Per capita Electricity Consumption (kWh)
Electricity (kWh)
14000
12000
10000
8000
6000
4000
2000
0
World
N America
Europe
MidEst+N Africa
CentAm+Carib
S America
Asia
Developed
Developing
H Income
M Income
L Income
Botswana
Region


Per Capita Petrol Consumption (Liters)
Petrol-Transport (Liters)
1600
1400
1200
1000
800
600
400
200
0
World
N America
Europe
MidEst+N Africa
CentAm+Carib
S America
Asia
Developed
Developing
H Income
M Income
L Income
Botswana
Region


Per Capita Diesel Consumption (Liters)
Diesel - Transport (Liters)
500
400
300
200
100
0
World
N America
Europe
MidEst+...
CentAm+...
S America
Asia
Developed
Developing
H Income
M Income
L Income
Botswana
Region


Primary Energy Mix
Primary Energy Mix
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
World
N America
Europe
S America
Asia (ExclChina)
Africa
Botswana
Region
Other
Nuclear
Hydro
Gas
Coal
Oil
Wood

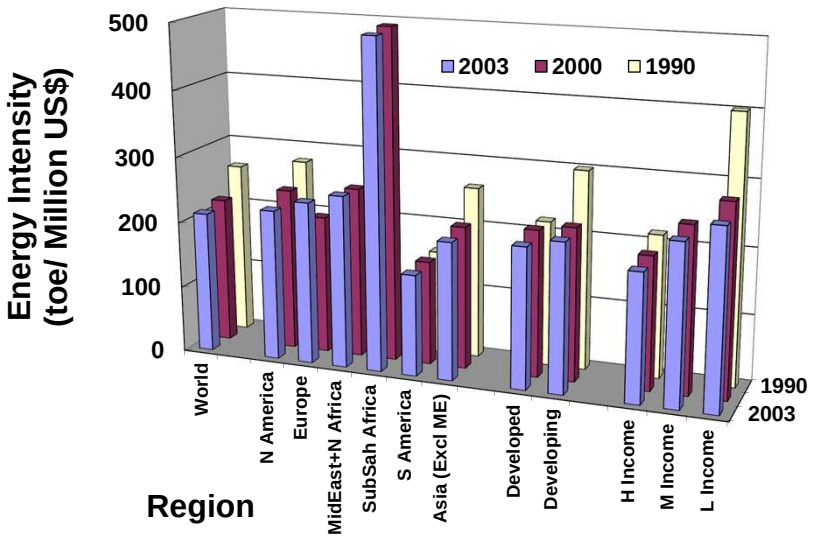

Sector wise Energy Use
Percentage Energy Use
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
27.5
16.5
27.5
16.5
35.3
56.2
21.3
35.7
World
N America
Europe
S America
Asia
SubSahAfr
Developed
Developing
Region
Other
Agriculture
Comm+Services
Residential
Transport
Industry



5.4. Energy Intensity

Energy Intensity → Energy used to generate one unit of GDP in products and services.

- It depends on the sector, namely Industry, Agriculture, Services etc.
- However, from the overall energy intensity we can get a general view of how effectively the energy is used.



6. Environmental Degradation and Energy Use

- World Energy → 80% Fossil Fuels + 10% biomass. → Degradation of air, land and water.
- **Atmospheric Pollution:**
  - ✓ **Green House Gases: About 68% of world wide GHG are energy generated.**
    - o Carbon dioxide
    - o Carbon monoxide
    - o Oxides of nitrogen
    - o Methane
  - ✓ **Non GHG Emissions:**
    - o Oxides of sulfur
    - o Lead and mercury
    - o Suspended particles.
    - o Volatile Organic compounds
- **Water pollution:**
  - o Acid Rain
  - o Pollution of Ocean
  - o Surface and ground water pollution.
- **Land Degradation:**
  - o Deforestation
  - o Desertification
  - o Acid rain leaching
  - o Waste disposal
- **Radioactive Pollution**






7. Energy Indicators of Development

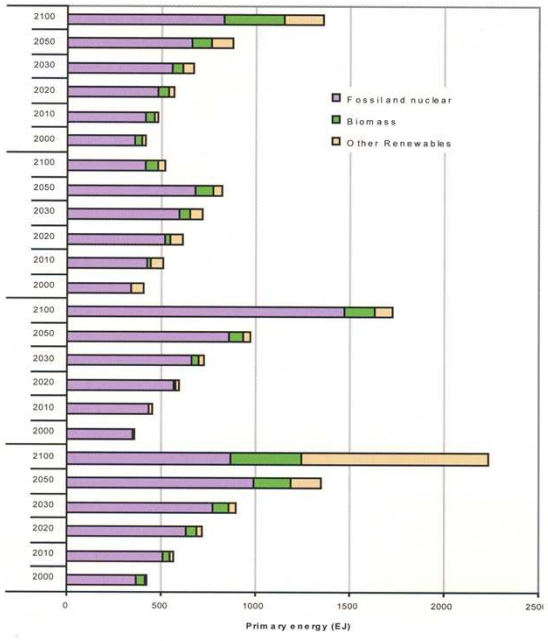
- Social and cultural development results in increased energy consumption.
- Population and industrial growth demand increased energy supply.
- To support industrial growth more commercial energy sources need to be supplied, and infrastructure for their distribution must be expanded.
- Affluent societies consume more energy from commercial sources to support their luxury life style.
- Usage of a large quantity of traditional energy indicates that a large proportion of the population is underdeveloped, remote, and rural and have an inadequate energy infrastructure.

- 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 energy is deployed in various sectors of the economy, and how successful the energy conservation initiatives are.
- Increased consumption of fossil fuels leads to increased environmental degradation. Appropriate measures must be put in place to minimize their use and maximize environmental protection while sustaining development.

8. Energy Security and Sustainability.

- Present Energy Consumption comprises of:
  - 17% Electricity.
  - 44% Low temperature heat.
  - 10% High temperature industrial heat.
  - 29% Transport fuels.
- About 2 Billion people worldwide have no energy services.
- Another 2 Billion have inadequate and unreliable energy services.
- ***Energy Poverty*** prevails predominantly in developing and underdeveloped countries.

- There is an uneven distribution of the predominantly used energy sources (the fossil fuels) amongst the countries of the world.
- As developing countries embark on development, their energy demand will grow at a faster rate than that of the developed countries, and a large fraction of it should be supplied by commercial sources.
- The graph in the next slide gives 4 scenarios of energy demand projections up to 2100 considering various combinations of assumptions, namely:
  - Population, and industrial growth.
  - Technological development
  - Resource availability
  - Environmental pressure …



- From the graph we note that:
  - Energy demand shall continue to grow (obvious).
  - Fossil fuels shall continue to play an important role in the world energy mix.
  - The contribution of renewable energy technologies shall also increase.
- Considering all these factors, countries will have to meet the increasing demand of energy with a mix of sources that may not be available within their borders.
- Under these circumstance one cannot talk of self sufficiency in energy, rather energy security and sustainability shall be the guiding factors.
- Energy security of not only the developing countries but also of the developed countries could be threatened.

- **Possible Threats to Energy Security:**
  - Instability and conflicts in regions where energy sources are concentrated (Oil, Gas and Coal).
  - Using energy supply as a weapon of negotiation/war.
  - Military actions to secure energy supply.
  - Natural calamities affecting energy production and supply.
  - Breakdown in the energy production and supply chain.
  - Inadequate investment in the energy production and distribution sector.
  - Terrorist threats targeting energy production and supply sector.
  - Market volatility.

- **In order to counter these threats, and to attain energy security/ sustainability, countries must:**
  - Increase domestic production and rely as much as possible on indigenous sources.
  - Diversify the energy mix so as not to depend heavily on any one source and on energy import.
  - Hold 90 days reserve of imports in the previous year, and in case of disruption of 7% or more in supply, share reserves with IEA member countries. (IEA).
  - 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, and as the fuel prices shall soar with reserve depletion + demand:

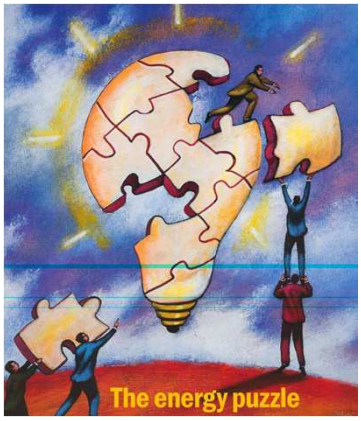
✓Old reserves which were uneconomic to mine shall become economically viable and shall be reopened.

✓Will have to go deeper, farther and to more remote locations in search or new reserves.

✓Less used unconventional sources like peat, tar and tight sands and shale shall have to be exploited fully.

If we do not act wisely, the future shall be:

→



•Energy is a very complex multidisciplinary field, like a 3-dimensional jig-saw puzzle.
•This evening we could glimpse only a few pieces of the puzzle, which revealed only a small corner of the picture.
•Many more pieces still remain hidden from view.
•However, in the interest of time we must move on to the last, but my very pleasant duty of Acknowledgements and Thank you's: →

Acknowledgements (1)

- **Photo Credits:**
  - GTZ GmbH, Germany
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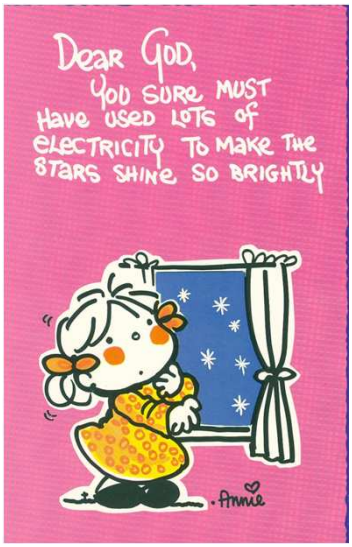

I thank you all for your attention and attendance.

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