Analysis of solar energy production, utilisation and management for facilitating sustainable development in and around the deserts of Pakistan

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Abstract

The problems of lack of potable water, food and electrical power in and around the desert environment are analysed and their solutions based on the utilisation of indigenous renewable energy resources are evaluated in the current research. Self-contained, decentralised solar energy powered processes are devised in the research results as means to attain the objectives of supplying electrical power, potable water and food to the communities living in the deserts in environmentally sustainable manner.

Needs analysis of desert community, a questionnaire survey, desert energy model utilisation scenarios, solar potential assessment and environmental emissions reduction strategy are used as means of analysis in the current research. A potential assessment of a desert site Islamkot, at Thar is carried out to demonstrate the capability of available solar potential to meet the energy needs of underground pumping, desalination of aquifer water potable water, cultivation of wheat, rice and pulses and domestic power consumption. The needs analysis estimates the amounts of electrical power needs of potable water desalination, agricultural commodities cultivation and electrical power needs per person per day, which can be scale up for any number of communities living in and around the deserts.

The results reveals that indigenous solar potential capability can be used to produce the required amounts of electrical power to meet the water, wheat, rice, pulses, electrical power, drinking, non-drinking and cultivation water needs of the desert communities in environmentally sustainable manner.

The research results are practicable and can be implemented to meet the energy needs of isolated communities living in and around the deserts in the long run. However, sustainable efforts would be required to encourage stakeholders to initiate a process of small, medium and large scale solar power utilization in and around the deserts.

Declaration

That no portion of the work referred to in these thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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Dedication

To my mother, father, wife, son and daughter, whose prayers, affection and support enabled me to pursue my studies in due course of time.

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Acronyms

AC	Alternate Current
AEDB	Alternative energy technology board, Islamabad, Pakistan
CDT	Cadmium telluride
CEPA	Clean Energy Project Analysis
CIGS	Copper indium gallium diselenide
CSP	Concentrating solar power
CSS	Carbon sequestration and storage
DC	Direct Current
DESERTEC	Foundation for using solar and wind energy
E	East
EPA	Environmental Protection Agency
GHG	Green House Gases
GT	Giga tonnes
GW	Giga Watt
HDI	Human Development Index
HSE	Health, Safety and Environment
HVDC	High voltage direct current
IRR	Internal Rate of Return
J	Joules
Kg	Kilogram
kJ	Kilo Joule
km	Kilometre
km^2	Kilometre square
kPa	kilo Pascal

kWh	Kilo Watt hour
kWh/m^2	Kilo Watt hour per kilometre square
LS-PV	Large Scale Photovoltaic System
m^2	Metre square
m^3	Metre cube
MED	Multi Effect Distillation
MENA	Middle East & North Africa
MFD	Multifactor distillation
Mha	Million hectares
MIST	Masdar Institute of Science and Technology, Abu Dhabi
Mm	Millimetres
MOW	Map of World
MSF	Multistage flash
MT	Metric tonnes
MW	Mega Watt
MWh	Mega Watt hour
MWh/m^2	Mega Watt hour per kilometre square
NASA	National Aeronautics and Space Administration
PCF	Prototype Carbon Fund
PDPUP	Pakistan Desert Power Utilisation Project
PICRET	Pakistan council of renewable energy technologies
PJ/m^2	Peta Joules per metre square
Pk Rs	Pakistani Rupees
Ppm	parts per million
PV	Photovoltaic

RO	Reverse osmosis
SG&A	Sales, General and Administration
SPREE	School of Photovoltaic and Renewable Energy Engineering
T CO_2	Tonnes of carbon dioxide
T	Tonne
TDS	Total dissolved salts
TJ	Tera Joules
$TUPTW_h$	Tonne urea per tonne of wheat
TV	Television
U	Urea
UAE	United Arab Emirates
UNEP	United Nations Environmental Programme
UNEPCCEE	United Nations Environment Programme Collaboration Centre on Energy and Environment
VCD	Vapour compression distillation
W	Watt
W/m^2	Watt per metre square
WEC	World energy council
WRI	World resource institute
yr	Year

Symbols

$	Dollar
%	Percentage
$(NH_2)_2CO$	Ammonium carbamade
¥	Renminbi-Chinese currency
Bar/barg	10^5 Pascals
C	Degree Celsius
Cal	Calories
Cl_2	Chlorine
CO_2	Carbon dioxide
Exa	10^{18}
H	radiation
H_2O	Water
N_2	Nitrogen
N_2O	Nitrogen oxide
NaCl	Sodium chloride
$NaHCO_3$	Sodium bicarbonate
NaOH	Sodium hydroxide
NH_3	Ammonia
NH_4	Ammonia
SO_2	Sulphur dioxide
TCO_2/yr	Tonnes of carbon dioxide per year
η	Efficiency

Greek symbols

μ	micro
ºC	Degree Celsius
δ	Delta
ε	Sigma
μ S/c	Siemens per centimetre -SI unit of electrical conductivity

Chapter 01 Introduction

1.1. Introduction

Humans cannot survive without energy and a certain amount of daily intake is essentially required to avoid a condition leading to starvation. To survive, a human requires at least the level of energy amounting to 5443 Joules a day, and if less calories are consumed, it could cause death due to starvation (Edlin and Golanty 2000). An active person weighing 65 kg consumes about 8374 to 10467 Joules per day, which is equivalent to 3 kWh power consumption (MacKay 2008). These amounts of energy are produced from food and water. The question arises as to whether the necessary amount of energy can be provided to all the areas equally, especially in the isolated places such as deserts.

Unfortunately, the answer is negative, as adequate amounts of food and potable water are not available in the same volume because of the lack of existence of sustainable energy generation and supply system. Therefore, neither basic needs such as water, food and domestic electrical power are adequately satisfied nor are the other needs such as transport, medical care, employment, entertainment and business and community development.

The ultimate effects of not being able to meet these needs are visible from poor social and economic indicators such as poor diet, low levels of water consumption, poor socio-economic conditions, low agricultural productivity and a low human development index. The Human Development Index (HDI) implies whether a certain region is developed, still developing, or underdeveloped based on factors such as life expectancy, education, literacy and gross domestic product per capita. The HDI is calculated as the simple average of life expectancy, education, and GDP index (Caliendo 2000). Pakistan's ranking on the human development index is not good in the South Asian region. According to (Haq, 2011), the human development index of Pakistan was 0.504 in the year 2011 and stood at 125 among 169 nations in comparison to its previous position in the year 2010 of 123. Further according to (Haq 2011), the human development index differences further exist in the urban and rural areas. For instance the human development index of Karachi is the highest in the country.

Since fertile regions are blessed with natural water resources such as rivers, lakes, springs and wells, they are rich in agriculture and get adequate cultivation water regularly. These areas get water through either the water supply or the irrigation supply system. However, the people living in desert regions are deprived of these facilitate and suffer from the conditions of droughts and starvation. Desert communities receive inadequate diets with a cost to their health, and suffer from chronic health problems (Harvey 2005). Therefore, these communities move from their original places to fertile regions in search of these commodities. There are socio-cultural effects of such movements, as these communities lead either a nomadic or semi-nomadic life.

It is considered unfeasible under centralised power and potable water supply system to supply either potable water or electric power to remote areas such as deserts due to the involvement of large expenditures for transporting electricity from the central grids or potable water from the water supply located in cities (Smith 1995; Zaigham 2001). Consequently these communities use environmentally unsustainable sources of energy.

Apart from these threats in solar-rich countries, certain opportunities exist such as the opportunity for low cost desert land, underground aquifer water and high radiation solar energy. Solar energy is readily available in solar-rich countries and can be used as a source for power generation, water heating, agricultural cultivation and water pumping (Harijan et al 2007).

All these opportunities can be explored for launching a process of sustainable energy generation and development in these areas. The socio-economic situation in these deserts can be changed if self-contained and decentralised electrical power and potable water production systems are utilised. Process of sustainable development in the deserts would have positive impact on socioeconomic sectors (Zaigham 2001; Shah and Zhang 2011).

It is essential to attempt both innovation and a renewable approach to produce the required amount of energy to meet the potable water, food and electrical power needs of inhabitants in these isolated and barren desert areas (Brady 2006). These processes can facilitate a process of reclamation of desert land and rehabilitation of desert communities by agricultural productivity and by preventing the process of migration by these communities to towns and cities.

The development of desert and vicinity areas would also resolve the problems of drought, dryness, and land barrenness. These communities use dung and wood for heating and cooking, which affects their environment and health. The use of solar powered heating, lighting and cooling would discourage the use of fossil fuels. The use of non-fossil fuel could have a positive impact on the environment.

The utilisation of solar energy in the desert would ultimately lead to the human resources utilisation process in the deserts. Considerable amounts of development foreign aid are received each year by the developing countries. For instance in 2008, the total aid received by Pakistan under military and economic cooperation was 1.685 billion US dollars and 1.3669 billion US dollars, which is around 3.094 billion US dollars (Ibrahim 2009). The use of aid programmes for the development of a sustainable energy mechanism would ultimately increase the human development index of desert regions.

If regional and foreign development aid programme is used for the development of self-contained solar energy utilisation systems in the deserts, it would also stop the process of migration to the adjacent towns and cities. In the event of stopping migration, it would be possible for the towns and cities to manage effectively and efficiently their limited supplies of potable water, electrical power and sanitation for the existing population.

1.2. Research question

The research question is centred on the hypothesis as to whether environmentally friendly energy generation and supply systems based on the utilisation of indigenous renewable energy resources could be devised to meet the electrical power, drinking water, non-drinking water and cultivation water needs of the people living in and around the deserts in an environmentally sustainable manner.

The research can be generalised for isolated rural communities, which also suffer from a lack of basic amenities due to the non-utilisation of a self-contained renewable powered energy generation and supply system. However, in view of the scope of the current research, the focus of the research is confined to per person per day in a desert community at Islamkot, Thar, Pakistan. The focused approach is aimed at carrying out an exhaustive needs analysis and solar potential and environmental emissions reduction assessments of the proposed site.

The scope of the research is confined to examining the prospects of meeting drinking water, non-drinking water, wheat, rice, pulses and electrical power needs per person per day in an environmentally sustainable manner for a desert community at Islamkot, Thar Pakistan. Since there are generic characteristics of solar-rich desert areas, it makes the research applicable in the context of other deserts regions in Pakistan such as Thal, Cholistan and Kharan.

1.3. Research hypothesis

In order to search for the answers to the research question, a hypothesis is developed. The main hypothesis is that

"All the power, potable drinking, non-drinking and agricultural cultivation water needs of people living in and around Thar, Pakistan could be met in an environmentally sustainable manner by the utilisation of solar energy potential over a small area of desert land".

The research assumptions and objectives are established for a systematic development of the proposed research hypothesis, to test the validity of the main hypotheses, and to gain the results. These assumptions and objectives are described in the following section.

1.4. Research assumptions

The research assumes that the process of potable drinking water production, agricultural cultivation and electrical power generation could be initiated in the deserts to improve the quality of life of these communities and to stop the process of migration of these communities to other areas, which takes place by people in search of these commodities. It is presumed that such development would have a positive impact on agrarian economy, as considerable amounts of barren land can be reclaimed by the agricultural development in the short term and by the process of setting up commercial units in the long term.

An energy analysis and generation and supply system per person per day for a desert community is carried out at the Thar Desert site in order to work out modalities for the development of desert areas and communities.

It is also assumed that an energy assessment process can be used to test the capability of available solar potential for supplying the needs of drinking water, non-drinking water, cultivation water and electrical power.

It is presumed that the climate data provided for Islamkot, Thar, Pakistan in the RetScreen software is verifiable and can be used for the assessment of the solar energy potential and emissions reduction.

A desert energy model scenario IV is presumed to be utilised ultimately for meeting their electrical power and potable water needs. The solar powered energy model presumes that carbon di oxide emissions could be avoided because of the non use of fossil fuels for the generation of the required amounts of energy.

Social, economic, technological and infrastructural barriers which may be emerged in the way of the construction of large scale solar power generation and desalination plants are presumed to be overcome in the light of the volume of sustainable development that could be brought in these areas.

1.5. Research aims and objectives

The aim of the research is to evaluate the prospects of development of sustainable energy generation and supply system to cater the needs of communities living in and around the deserts. The research objectives include analysis of the total volume of drinking and nondrinking water, wheat, rice and pulses per person per day in a desert community and the calculation of the total amounts of energy (electrical power) required per person per day. The gist of research aims and objectives is provided below.

1. To determine the nature and the amounts of basic needs such as drinking, non-drinking and cultivation water, food and electrical power per person per day for a desert community.

2. To determine the total energy amounts required for the production of the estimated quantities of drinking, non-drinking and cultivation water (m^3), food (10^3 kg) and electrical power (kWh) per person per day for a desert community.

3. To evaluate the capability of a solar energy per square metre per day (kWh) at Islamkot, Thar, Pakistan.

4. To analyse the positive impact of proposed sustainable energy development programmes on the socio-economic and cultural spheres of desert communities.

5. To identify the risks associated with the development of solar powered electrical power generation processes.

6. To identify the health, safety and environmental risks associated with solar power generation and to devise remedial measures.

7. To establish the worth of desert energy utilisation energy model under various scenarios.

1.6. Research goals

Needs analysis, mass and energy balance, solar potential and emissions reduction assessment per person per day are developed as the goals. These goals are described in detail below.

1.6.1. Determination of the total needs (kWh) per person per day for a desert community

The goal of identitification and estimation of basic needs such as drinking, non-drinking, cultivation water electrical power and food is established**.** In order to attain a balance in the energy demanded and supplied are maintained.

The volume of water in measured in m^3, and the quantities of food are measured in tonnes. Electrical power consumption and generation units are measured in kWh. In the whole process, needs and luxuries are categorized, so that the wastage of limited resources can be discouraged at all levels especially at the preliminary stage. In this regard, the systems for checks on energy consumption limits and rewards are proposed, especially the award of incentives to those who support energy saving measures and activities.

1.6.2. Calculation of total energy requirements (kWh) per person per day

Since human needs are fulfilled at the cost of energy, the goal of calculating the required amount of energy consumption is set. Energy would be required for the processes of aquifer water pumping, desalination of drinking, non-drinking and cultivation water and domestic power consumption. The estimated amounts of drinking, non-drinking and cultivation water and electrical power consumption are per person per day in a typical desert community.

The total energy needs per person per day for a desert community are calculated in kWh, on the basis of the energy consumption in pumping and desalination of drinking, on-drinking and cultivation and domestic power consumption. in the Chapter Four.

The goal of estimation of total energy required and expected environmental emissions reductions is included in order to familiarise with the amounts of emissions that can be avoided per person per day. The break down of the amounts of energy generated and emissions reductions is provided in the section on the results in Chapter Six.

Solar power storage is also established to ensure an uninterrupted power supply system in the day and off-solar hours. Power Plan A storage is devised for solar power generation during the day to meet the normal power needs of desert communities. Power storage Plan B storage includes an electrical power storage system in an isolated grid to cater for electrical power needs in off-solar hours.

1.6.3. Comparison of proposed energy generation strategies with existing means of water treatment and electrical power supply

The goal of comparison of solar energy generation system with non solar systems is set. A questionnaire survey is used to gain an insight into the nature and volume of existing processes and to obtain the viewpoints of experienced personnel engaged in thermal and solar power generation and desalination industries and for a comparative analysis of ongoing solar powered electrical power generation and desalination systems. The survey results contributed considerably to the analysis of the prospects of the proposed electric power and potable water processes.

The survey is based on the variables such as the nature of input energy sources, energy consumption in kWh, production costs in $ and carbon dioxide emissions releases (kg). Open and closed type questions are used to extract the required information from the professionals and technocrats working in these industries existing processes. The ultimate goal is to determine whether there are prospects of solar power system and to evaluate if a need for a sustainable alternative fuel is felt in these industries, to resolve the problems of fossil fuels and environmental emissions in the short, medium and long term.

1.6.4. Evaluation of the prospects of the desert community development process

The goal of evaluation of positive changes in the economic, social and cultural spheres, such as development of an agrarian economy in the desert and stopping the process of movement of desert communities to other areas, the resolution of the problems of poverty, unemployment, land barrenness, poor health, and lack of sanitation is also included.

The measure of funding for renewable energy powered projects from provincial and local government development programmes and international and regional aid programmes is also discussed. The benefits of proposed research on the desert economy such as reclamation of desert land, and rehabilitation of desert communities, community development and an increase in the agricultural output are also evaluated.

Finally, the prospects of bringing welfare in and around these desert areas is evaluated on the basis of their potential contribution to existing power generation and potable water production capacities.

1.6.5. Use of a desert energy utilisation model

The goal of development of a desert energy utilisation process is established to facilitate the process of available solar energy to attain the objectives of socio-economic stability and to end economic disparities. Desert resource utilisation issues are addressed and various scenarios such as I, II, III and IV are discussed. The goal of the calculation of total electrical power consumption under each scenario is also estimated.

1.6.6. Evaluation of associated risks

The goals of study of the risks associated with the supply of electrical power during off-solar hours, subsequent changes in consumption patterns, tentative plant operation problems and the maintenance issues of the solar power project are set in order to study their effects and to devise measures to preclude the possibilities of plants breakdown.

It is assumed that the problems of plant maintenance could be resolved by a scheduled and preventive maintenance system. It is presumed that health and safety of the plant and personnel could be ensured by the implementation of health, safety and environmental laws and practices. The prospects of the implementation of health, safety and environment procedures in the premises of the proposed plants are discussed.

The potential environmental, health and safety hazards associated with solar power generation and plant personnel, such as the release of emissions during decommissioning or disposal of solar phototovoltaic panels are also addressed. The likelihood of damage to local fauna is also evaluated.

1.7. Summary of the thesis

The thesis is divided into eight chapters. It comprises of an introduction to the research, the literature review, needs analysis, desert energy models, results and analysis, discussions and conclusions and recommendations.

Chapter One gives a brief resume of the research, the research question, the main hypothesis, research assumptions, research aims and objectives, methods of attaining research objectives, and a summary of the thesis chapters. An introduction to the research methodologies such as: questionnaire survey, needs analysis, energy and mass balances, desert energy development model scenarios, solar energy potential and emission reduction assessment processes are described in Chapter Two.

The literature review includes the study of existing energy scenarios, global energy challenges, fossil fuels, their limitations, possible solutions, sustainable energy options, solar energy potential, the deserts (their types and their problems), solar potential in solar-rich deserts, their utilisation prospects, the role of solar energy technology utilisation in deserts, solar thermal and solar photovoltaics processes technologies, ongoing desert power projects, solar potential assessment in the deserts of Pakistan, desert communities, problems of desert communities and sustainable development processes in deserts are reviewed in the Chapter Three.

The desert communities, their problems, an energy scenario analysis, needs analysis on the amounts of potable drinking, non-drinking and cultivation water, electric power and agriculture commodities per person per day is carried out in Chapter Four. The desert energy utilisation model scenarios I, II, III and IV are devised and analysed in Chapter Five, along with the analysis on the issues associated with each model. The results on the analysis of solar energy potential and CO_2 emissions reduction assessment and questionnaire survey are produced and analysed in Chapter Six.

In Chapter Seven, discussions on the level of success in attaining the research objectives and possible means for the success of solar powered energy systems are discussed. The prospects of large scale energy generation processes are also discussed. The general issues pertaining to the implementation stages of the proposed projects are also evaluated.

The conclusions, recommendations and the future work are provided in Chapter Eight. In the Appendices A, B and C, the questionnaire survey details, journal and conference publications are attached.

Chapter 02 Research Methodologies

2.1. Introduction

The literature review, needs analysis, desert energy utilisation model scenarios, mass and energy balance, solar potential and emission reduction assessments and questionnaire survey are all used in the research process for evaluation, compilation and analysis in the research. A detailed literature survey is carried out in order to demonstrate not only an underlying knowledge and understanding of the key issues and concepts concerned with the content of this thesis, but also to critically evaluate the literature's contents, which might be potentially relevant to the conduct of the programme of research.

Mass and energy balance is used to attain the objective of attaining a balance between the total amounts of energy required and the total amounts of commodities to be provided per person per day in a desert community at Thar, Pakistan. Solar potential assessment and environmental emission reduction analysis is carried out to evaluate the capability of solar power generation to avoid anthropogenic emissions reduction.

Desert energy utilisation model scenarios cater for the production of the estimated amounts of electrical power and potable water by the utilisation of desert inputs including solar energy, brackish water and desert land space. The scenarios I and II reviews the prospects of production of chlorine, sodium bicarbonate and urea, electric power and potable water s. Scenario III, besides the outputs produced under scenario II, evaluate the scenario of the use of Thar coal revenues to finance the solar photototvoltaic plant costs. The desert energy utilisation model scenario IV examine the prospects of elimination the processes of brine electrolysis, air separation, ammonia synthesis and urea synthesis with the aim of optimising total energy required and costs.

Needs analysis process is carried out to identify and estimate the amounts of basic needs such as drinking water, non-drinking water, water required for the cultivation of wheat, rice, pulses and electrical domestic power consumption per person per day in a desert community.

Solar energy analysis is used for the evaluation of the capability of solar power potential and the total area of desert land that would be required. CO_2 emissions reduction assessment is used for the calculation of the volume of CO_2 emissions that can be avoided by the use of solar energy as an energy fuel.

A questionnaire survey about the fossil fuelled and solar powered electrical power and potable water processes is carried out to evaluate the nature of energy sources, volume of energy used and environmental effects of fossil-fuelled processes.

2.2. Literature review

A survey of the literature on the topics including: the nature of existing generation systems, limitations of fossil fuels, potential of renewable energy sources, conventional energy generation systems, deserts, their problems, available opportunities, self-contained desert energy systems, solar energy technologies, desert communities and their problems, desert communities in Pakistan and the positive impacts of desert power generation on existing electric power, water and food production capacities.

The developments in the area of desert power, power generation and desalination processes are also reviewed. Since considerable progress has been made in deserts in various regions of the world, their advantages, disadvantages and prospects are analysed with special reference to the prospects for solar powered sustainable development in the deserts of Pakistan. These areas have provided sources for information on the low opportunity costs of desert land and valuable solar potential.

The literature highlights the loopholes and the consequent disparities in the system of fossil fuelled energy generation and supply system to low density populations living in far flung areas in the energy deficient developing but solar-rich countries, and discusses the importance of indigenous renewable energy sources in building an energy generation and supply system in such places.

The negative effects of the fossil fuels on the environment and economy such as high fossil fuel prices, release of anthropogenic environmental emissions and global warming are reviewed. The effects of lack of energy generation and supply system are also reviewed.

Problems in the supply of electrical power to the communities in the deserts are also analysed and possible energy generation and supply options for the deserts are also reviewed

2.3. Questionnaire survey

A questionnaire survey of existing electrical power generation and potable water production processes is carried out in order to analyse and compare fossil fuelled and solar powered processes. Pilot questions were sent before the main questionnaire to obtain information on the nature of questions for the questionnaire survey**.** The questionnaire survey is based on the variables of the volume of input raw materials, the range of production costs, the amounts of environmental emissions released and environmental sustainability of fossil and solar energy generation systems. The samples of the questionnaire survey were taken from power generation and water treatment companies of Pakistan and from the Masdar Institute of Science and Technology, Abu Dhabi, UAE.

The response rate of the questionnaire was 40%. The overall impression of the solar power and desalination processes, in comparison to fossil fuelled power generation and desalination systems was positive on account of the renewable nature of solar energy, low emissions releases and zero fuel costs.

The respondents were selected on the basis of their qualifications and experience in thermal and solar power, water treatment and desalination processes. Demographic aspects of the samples such as age and sex are also covered in the questionnaire survey. All the respondents are male and are in the age group of 30-50 years, and are working in middle and senior level positions.

The results, recommendations and the suggestions from the survey's respondents enabled the author to analyse the advantages and disadvantages of both existing and proposed processes. The results on thermal power generation, solar power generation, conventional water treatment and solar desalination processes are analysed in the section on results of the questionnaire survey in Chapter Six.

The survey is helpful in the supplying information on the volume of energy consumption, the volume of CO_2 emissions releases, the range of production costs and environmental sustainability aspects of fossil fuelled and solar powered processes. The possible barriers that could prevent the realisation of the objective of large scale solar powered power generation and desalination processes and their recommendations to overcome these barriers were also covered in the survey.

2.4. Needs analysis

The needs analysis process includes information on the nature and volume of the basic needs of the people living in the deserts. In this section, the amounts of their basic needs are identified and estimated.

The analysis covers existing consumption patterns of drinking, non-drinking, cultivation water and agricultural commodities such as wheat, rice and pulses and electrical power. The total needs of per person per day in a desert community including electrical power; drinking, non-drinking and cultivation water and food commodities are estimated. The break down of the needs analysis of small and large desert communities is provided in Chapter Four.

The cultivation water for wheat, rice and pulses are estimated on basis cultivation water crop production consumption standards in Pakistan. The total potable water is estimated on the basis of their consumption for drinking, nondrinking and cultivation water per person per day. The total electrical power required is estimated on the basis of their consumption on pumping, desalination and domestic electric power consumption per person per day in a desert community.

The total energy is calculated in kWh, which is the sum of energy consumption for the desalination of drinking, non-drinking and cultivation water and electrical power consumption per person per day.

In the solar energy analysis, the power generation capacity and the solar collector area are measured in kW and m^2/km^2.The daily solar radiation data of the nearest location Islamkot, Thar, Pakistan is used for the measurement of power generation capacity and the solar collector area. The measurement of the solar collector area is calculated on the basis of the solar radiation available and electrical power generation capability per metre square per day.

Only basic needs are, however, covered in the analysis. However, it is proposed that the amounts of these needs could be increased in the future. It is also anticipated that scale of solar power generation could be stretched to accommodate the possible increases in these needs on account of increases in the population and changes in living styles.

2.5. Energy and mass balances

Energy and mass balances are used for attaining a balance between the total amounts of energy required and the total amounts of commodities that would be consumed per person per day in a desert community. This total amounts of commodities and total amount of energy are measured in 10^3 kg and kWh. The diagram for mass and energy balance is shown in Figure 2.1.

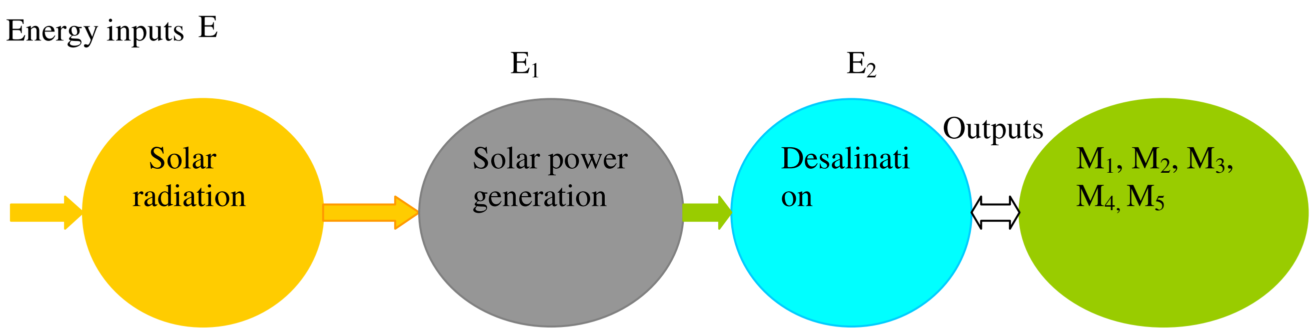


Figure 2.1. Mass and energy balance diagram

The mass and energy balance is given by the relationship, shown in equation (2.1.);

$$E_1+E_2 = M_1+ M_2 + M_3 + M_4 + M_5 \qquad (2.1)$$

Where;

E_1=Total energy required for electrical power generation (kWh)

E_2= Total energy required for desalination of drinking, non-drinking and cultivation water (kWh)

M_1=Total water required for drinking, non-drinking and cultivation (m^3)

M_2= Total electrical power required (kWh)

M_3= Total wheat required (10^3 kg)

M_4=Total rice required (10^3 kg)

M_5= Total pulses required (10^3 kg)

The total mass of commodities and total energy equivalent are maintained in order to avoid the problems of energy generation gaps in energy demanded and generated

2.6. Solar potential and CO_2 emissions reduction assessment

The energy generation potential is estimated for Islamkot, Thar, Pakistan. The solar radiation data for Islamkot and emission factors of Pakistan are used in the assessment process as inputs. In the energy analysis, the array losses (%) from miscellaneous sources are included, for example, losses due to the presence of dirt or snow on the modules, or mismatch and wiring losses. The power conditioning losses (%) are incurred in DC-DC converters or in step-up transformers and are taken into account.

The amounts of solar energy available that could be utilised at the proposed desert site are calculated in the solar potential assessment. The amounts of CO_2 emissions that could be avoided by not using fossil fuels in the generation of electrical power are calculated in the CO_2 emission reduction assessment. The amounts of energy generation and capacities are measured in kWh and kW. The carbon dioxide emissions are measured in kilogrammes. The capacity factor represents the ratio of the average power produced by the power system over a year to its rated power capacity.

2.6.1. Tools for solar potential and emissions reduction assessment of Islamkot, Thar

The tools provided in RETScreen IV, clean energy project analysis software, are used for solar energy generation and carbon dioxide emission reduction calculations. RET stands for renewable energy technology. In the energy analyses, the monthly mean values of global solar radiation on a horizontal surface, the monthly mean temperature and the site latitude are used as the input data to obtain the specific electrical power (energy yield) per day.

The module efficiency in the energy analysis depends primarily on the type of cell used (mono-Si, poly-Si, a-Si, CdTe, CIS, spherical-Si). There are wide variations in module efficiency from manufacturer to manufacturer, depending on the manufacturing processes used. Mono-Si solar cells manufacturer efficiencies (11.7%) are used in the analysis. The inverter has power conditioning losses (%), including losses incurred in the conversion of DC to AC current.

The PV array model is based on work by Evans and is common to all types of PV systems According to Thevenard et al (2001), the array is characterised by its efficiency, η_p , which is a function of its nominal efficiency and ηr is measured at a reference temperature T_r = 25C, as shown in Eq. 2.2.

$$\eta_p = \eta_r [1 - \beta\, Tc - T_r] \qquad (2.2)$$

Where β is the temperature coefficient for module efficiency and T_c is the module temperature. T_c is related to the mean monthly ambient temperature T_a through Evans formula, as illustrated in Eq. 2.3.

$$T - T = (219 + 832Kt)\, NOCT - 20\, /800 \qquad (2.3)$$

Where; K_t is the clearness index and *NOCT* is the Nominal Operating Cell Temperature of the type of module under consideration. According to Thevenard et al (2001), Eq. 2.3 is valid for optimally tilted arrays facing the equator. In other configurations a small correction is applied, depending on the actual tilt of the array. Furthermore according to Thevenard et al (2001), it is applied in the case of tracking surfaces, using the tilt angle at noon as the actual tilt angle.

However, the array efficiency, as is calculated in Eq.2 2 is reduced by two factors. The first one, λ_p represents miscellaneous array losses such as losses due to dirt or snow covering the modules and the second λ_c represents power conditioning losses such as those due to DC to DC converters or step-up transformers. The array power available to the load and the battery, E_A is given in Eq. 2.4

$$E_A = H_t \eta_{p(}\, 1 - \lambda_p)(\, 1 - \lambda c) \qquad (2.4)$$

Where; H_t is solar radiation that is incident upon the array. The grid-connected model is the simplest system model. The energy available to the grid is what is produced by the array and reduced by inverter losses, as shown in Eq. 2.5.

$$E_{grid} = E_A \eta_{inv} \qquad (2.5)$$

Where η_{inv} is inverter efficiency, this depends on the grid configuration. However, not all this energy may be absorbed by the grid. The energy actually delivered E_{dlvd} is given in the Eq. 2.6.

$$Edlvd = E_{grid} \eta_{abs} \quad (2.6)$$

Where η_{abs} is the PV energy absorption rate, which is equal to 1 for large grids and its range for small grids is between 0.95 and 0.98.

In the energy analysis grid tied power plants can be used with and without an internal load. For grid-tied power plants with an internal load the power in excess of the specified load can be fed into the grid. When an internal load is present, a "Load & Network" sheet is provided to provide input values for average power requirements of the internal load for each month and the peak load on an annual basis. For isolated grid projects with an internal load, there is a limit to the power that the isolated grid can absorb from the proposed power project (Thevenard et al 2001).

However, in a central grid or isolated grid project without an internal load, it is assumed that the entire output of the power project will be supplied to the grid, which is called "electricity exported to the grid". In such a case, a detailed description of the base case equipment, such as generators and transformers are not required (Thevenard et al 2001).

In the off-grid type, the base case parameters and load description depend on the project and technology type. In a single technology power process off-grid power projects such as photovoltaics, wind turbines, reciprocating engines or hydro turbines, the load in the worksheet is supposed to disappear and the sheet is expanded. The expanded sheet includes the base case power system, gas turbine, its fuel type, capacity and efficiency. In an off-grid single type project, the total DC demand, D_{DC}, and the total AC demand, D_{AC} are specified by the *user*. This latter is converted to a DC equivalent by dividing it by the average inverter efficiency η_{inv}.

In the emission analysis, the greenhouse gases that could be avoided by the usage of the solar energy are calculated in kg CO_2. The emissions analysis includes a base case greenhouse gas emissions reduction. The base case system is a fossil-fuelled power generation system (Thevenard et al 2001). The kilogrammes of carbon dioxide emissions that could be prevented from entering into the local atmosphere from the burning of fossil fuels of the quantities as a result of the use of solar energy are calculated. The levelised nominal costs for each tonne of GHG avoided are also calculated.

The emission analysis process is designed in collaboration with global environmental organisations. An standardized methodology is in collaboration with the United Nations Environment Programme; the UNEP RISØ Centre on Energy, Climate and Sustainable Development and the World Bank's Prototype Carbon Fund. Emission factors of respective countries used in the calculation of total amounts of emissions are validated by the team of environmental experts.

2.6.2. Tool for climatic data collection

RetScreen-IV software is used for climatic data of Islamkot, Thar, Pakistan. The data pertaining to latitude, longitude, elevation, heating design temperature, cooling design temperature, air temperature, relative humidity, daily solar radiation on a horizontal scale and atmospheric pressure is provided by the RETScreen climate data base (Rehman et al 2007).

Daily solar radiation used in the analysis is the amount of energy in $kWh/m^2/day$. There are provided variations in the duration of these energies in the summer, winter, autumn and spring seasons. The average atmospheric pressure determines the level of the proposed site; either at the lower or the higher end (high end corresponds to sea level). The mean atmospheric pressure can be estimated by the expression, shown in equation (2.7):

$$P = P_{sealevel} * e^{(-z/8200)} \qquad (2.7)$$

Where; $P_{sealevel}$ is the atmospheric pressure at sea level and Z is the altitude in metres above sea level. The unit of atmospheric pressure in kPa

There are certain climate data limitations. For instance climatic data for major cities in Pakistan is provided only. This could have implications for data collection of desert locations not provided in the climate data base.

2.7. Desert energy utilisation model scenarios

The desert energy utilisation model scenarios are developed for the utilisation prospects of desert resources such as high radiation solar radiation and aquifer brackish water. The energy model is solar phototovoltaic powered. The prime objectives of the desert energy utilisation model scenarios are to build an understanding on the use of environmentally sustainable self-contained energy generation mechanism in and around the desert areas.

In the desert energy utilisation scenarios, the quantities of inputs and outputs are calculated on the basis of the total needs and total energy requirements of people living in the desert communities. Four scenarios of the desert energy model are reviewed. In scenario I and II, the molar masses of inputs such as brine (NaCl), water (H_2O),nitrogen, ammonia (NH_3) and carbon dioxide (CO_2) and output products such as chlorine (Cl_2), hydrogen, sodium hydroxide (NaOH), sodium bicarbonate ($NaHCO_3$), Hydrochloric acid (HCl) and urea ($(NH_2)_2CO$) are calculated. Molar mass calculations of the input and output products are based on the production of potable water production

Certain assumptions are made in the desert energy model energy calculations such as the water recovery ratio and maximum amount of brine content in brackish water. The water recovery ratio is assumed to be 40% meaning that for every one tonne of brackish water 0.4 tonnes of potable water is recovered. The maximum amount of brine in seawater is assumed as 3.2%.

The energy calculation of the desert energy model for scenarios I, II, III and IV are carried out. The details of these calculations are provided in tables 5.1and 5.2 in Chapter Five.

Chapter 03 Literature Review

3.1. Introduction

The literature on the nature of existing energy sources such as fossil fuels, their limitation and environmental effects, prospects of renewable energy sources, solar energy potential, desert communities and their problems, available energy options, desert power generation in the deserts, solar power potential in the deserts of Pakistan and its impact on the current energy scenario is reviewed. The review is aimed at the evaluation of the advantages and disadvantages of each type of energy source and to analyse the possible means of achieving clean, affordable and environmentally sustainable energy generation and supply systems in and around the desert areas.

The issues associated with energy infrastructure and the development of self-contained energy systems is also reviewed. The renewable energy sources are reviewed to assess their contribution to the reduction of energy scarcity, environmental emissions reduction, expansion of existing energy capacities and cost optimisation. Energy generation processes and consumption patterns and the use of solar powered processes in the deserts of Pakistan are also reviewed.

The current energy situation in the rural and desert areas is reviewed. Possible solutions to the energy crisis in light of the poor standard of living of desert communities, environmental emissions, dependency on fossil fuels and energy supply insecurity are reviewed.

3.2. Characteristics of deserts

Deserts exist everywhere on earth and other planets. Climatically, there are two types of desert: cold and hot. The deserts are characterised by hyper aridity or true aridity. Hyper arid deserts have less than 24 mm of precipitation annually. Examples are the Sahara, Majova, Namib and Atacama deserts. Deserts are also classified as polar and the non-polar. The hot deserts are polar and the cold deserts are non-polar. Antarctica is a non-polar desert. The world's deserts are shown in Figure 3.1.

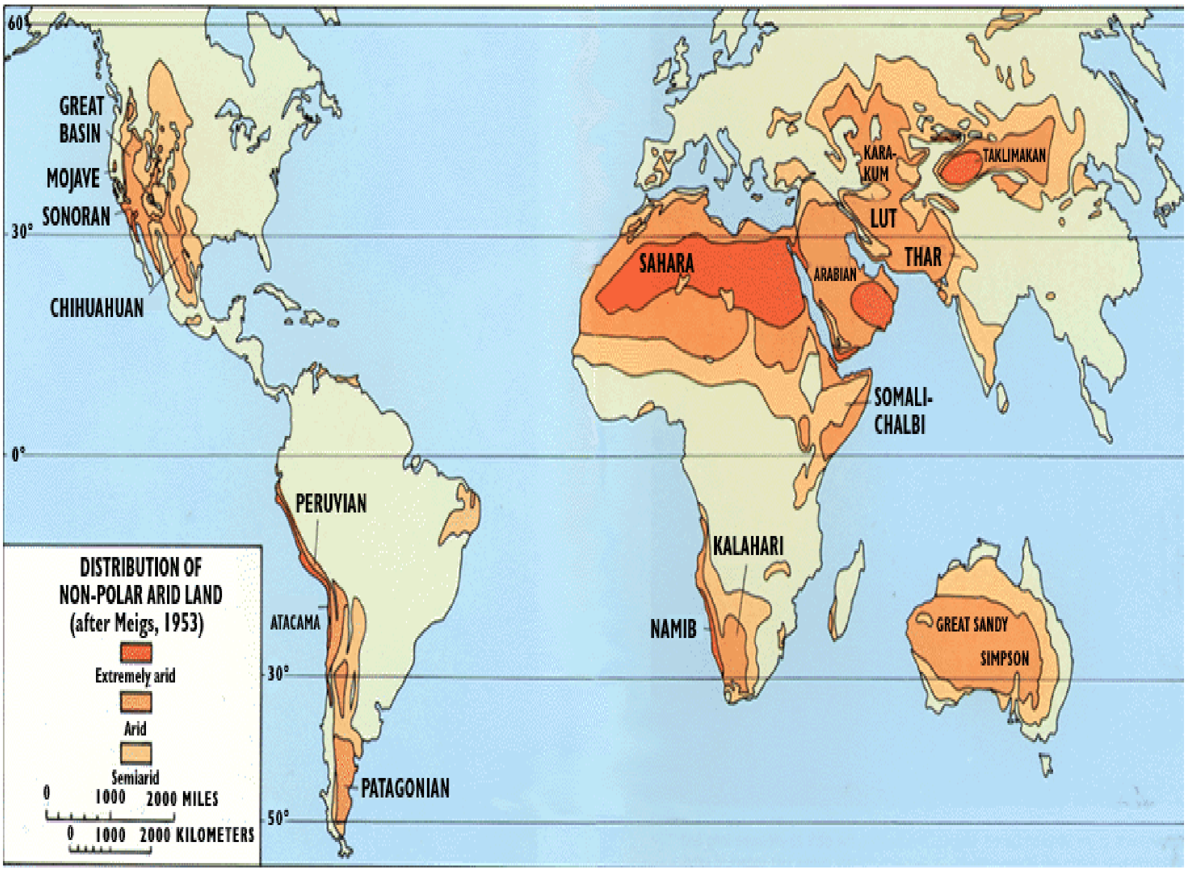


Figure 3.1. Deserts of the world (MOW 2011)

The hot deserts provide opportunities for high radiation solar energy (Loster 20101). These deserts are distinct from each other on the basis of dryness, age, climate, area, geography, geology and temperatures. The rains are less than 100 mm per year and the evaporation rate is high in hyper arid deserts, so they frequently suffer from long spans of droughts frequently (Gonflantini 1981).

The annual precipitation index varies in hyper arid, semi arid and arid deserts. The arid index for a hyper-arid zone is 0.03 and for an arid zone it is in the range of 0.03-0.20. According to FAO (1989), the index in a semi-arid zone arid is in the range of 0.20-0.50. Furthermore according to FAO (1989), annual precipitation varies from 300-600 to 700-800 millimeters, with summer rains, and from 200-250 to 450-500 millimeters with winter rains. The arid index in the sub-humid zone lies from 0.50-0.75.

People in deserts lead nomadic and semi nomadic lives in search of food and water for themselves and their animals. Though desert communities are rehabilitated in such environments with the passage of time, these communities suffer droughts frequently (Ahmed et al 2004).

Due to scarcity of water it is difficult to sustain animal and plant life in the hot deserts, as is evident by the occurrence of frequent droughts. Because of the land's dryness droughts are frequents, which has seriously affected the process of agricultural cultivation in these deserts. The problems of potable water and soil infertility are complicated with the passage of time (Kahlown 2004). These desert problems are described in the following sections.

However, if the problem of lack of availability of potable water is resolved, it could contribute to the development of sustainable plant life. Through the development of its indigenous resources, it is possible to protect the desert's unique plant life, and develop these desert regions. Solar power generation and desalination processes can be used for potable water production processes (Zaigham 2001).

3.3. Main problems of the deserts

The main problems in the deserts are unavailability of potable water, lack of food commodities, unavailability of electrical power, land barrenness and a poor socioeconomic infrastructure (Kahlown 2004). There are problems of loss of water due to a high evaporation rate and run offs in the deserts. There is also the challenge of low productivity due to low soil fertility in the desert environment (Bolonkin 2007).

Potable water could not have been provided adequately to these deserts due to the lack of utilisation of underground aquifer water desalination and indigenous renewable energy sources (Zaigham 2001; Shah and Zhang 2011). Development of indigenous water resources in the deserts instead of importing water from other areas could facilitate a process of development of these areas. It is time to establish necessary institutional, economic and management arrangements necessary for encouraging the use of self-contained renewable energy powered pumping and desalination plants (Shah and Zhang 2011).

3.3.1. Lack of agriculture

The desert lands are not utilised adequately for the purpose of crop cultivation and livestock grazing (UNEP 1998). Consequently, a considerable portion of the available labour force in the deserts remains un-utilised and their families suffer from starvation. These factors leave negative impacts on the agrarian economy, as large land areas remain barren and are not utilised either for agriculture or commercial activities in deserts.

Furthermore, deserts lack rivers and if there are lakes, these are generally shallow, temporary, and salty, and have a low bottom gradient (Bolonkin 2007). However, rain-fed irrigation such as spate irrigation is available, but these have limited application. Spate irrigation is a common practice of water management in regions bordering highlands. It is a form of water harvesting and managing unpredictable and sometimes destructive flash floods for crop and livestock production. There is a need to launch a combined strategy to turn these barren lands into fertile regions. Otherwise, the pressures on existing energy capacities are bound to increase in the cities (Bolonkin 2007).

It is possible to convert deserts into arable, green landscapes that can lead to better ecosystem function for plant health bacterial communities in agricultural soil (Kobert et al 2011). This objective can be attained by using underground brackish water by using solar power for pumping and desalination. According to Chen (1990), failure to develop such alternatives, however, could result in the consequences of hunger and world food scarcity. Agricultural outputs have positive implications on the local population. Further according to Chen (1990) and Kobert et al (2011), crop cultivation would have a positive impact on the environment, as the problems of soil infertility could be diminished.

3.3.2. Lack of potable water

More than a billion people in the developing world lack safe drinking water and three billion people live without access to adequate sanitation systems despite the presence of the international aid community, nations and local organizations to satisfy these basic human needs (Gleick 19990). The potable water supply situation varies in the urban, rural and desert areas. Due to scarcity of water it is difficult to sustain life in the hot deserts. Considerable losses to both men and materials are borne by the desert communities due to the problems of dryness and drought (Ahmed et al 2004). Stored rainwater in unclean wells, situated long distances apart is the only source of water for drinking in most of the deserts (Kahlown 2004)

The intensity of the water problem can be realised from the fact that the desert communities feels difficulties in the arrangements of even drinking water. The stored rain water is contaminated with the passage of time and its consumption which has resulted in an increase in the cases of dehydration.

Research projects were carried out at these deserts as to how to desalinate underground brackish water. For instance, an integrated research study on geoelectric scanning, drilling and seismic-data analyses was carried out to delineate subsurface hydro-geological conditions beneath the Thar Desert. According to Zaigham (2001), the results of the study revealed that perch water aquifers, commonly being utilized throughout the Thar, are present at the bottom of the dunes and-zone, with fluctuating yield controlled by the annual rainfall cycles. Furthermore according to Zaigham (2001), in Thar desert, approximately 48% of unclean dug well water contains electrical conductivity from 2000 µS/cm to more than 10,000 µS/cm; EC of 5,000 µS/cm is considered drinkable under duress for the arid region.

According to Kher (2008), the aquifers in the Thar Desert contains an estimated 150,000 cubic km of water and currently about 6.5 million cubic metres per day are being extracted over its entire extent covering parts of Sudan, Chad, Libya and Egypt. The water under the Thar Desert near to coastal areas in aquifers is a renewable resource**.** Furthermore according to Kher (2008), **e**xploiting this resource in places away from the coastal areas could deplete these resources in the long run.

3.3.3. Lack of electrical power

Due to the lack of self-contained energy systems and the involvement of high costs and expenditure in laying transmission lines to low density populations in and around the desert areas, it is not considered feasible to provide electric power to the communities living in isolated places. The communities that exist in and around the deserts of Pakistan also suffer from lack of electrical power supply (AEDB 2010). The lack of electrical power has hampered the process of development of environmentally sustainable energy supply system in far flung areas.

The ultimate effects of the lack of electrical power supply systems are evident from the use of obsolete fuels such as dung and wood for lighting, heating and cooking in and around the desert areas, which are replete with the release of anthropogenic emissions (Ghaffar 1994).

3.3.4. Desert land barrenness

Land barrenness is a major problem in the deserts, due to unavailability of a surface perennial water system. There are interdunal areas, which are favourable for agricultural activities, however there are no regular rotational crops in these desert areas (Zaigham 2001).

If the required amounts of agricultural water are provided, the process of cultivation can be initiated in these areas. Desert farming can facilitate the process of a growing area of agriculture and attaining the objectives of conservation of the ecosystem and plant health (Kobert et al 2011).

3.3.5. Lack of community development

A nomadic and semi-nomadic life culture is prevalent in the s communities living in and around the deserts areas. Pastoralists migrate along with their herds to find pasture and water for their animals and themselves (Nicholas et al 2001). There are 50–100 million nomads and semi nomads in the developing world, and over 60% of these populations live in Africa (Sheikh and Velema 1999).

According to Sheikh and Velema (1999), inequalities between nomadic and settled populations are due to the particular environment in which nomads live which is either directly or indirectly related to an absence of modern health care among nomadic populations. Furthermore according to him Sheikh and Velema (1999), formal education, health and human resource development could be provided when these communities are settled in their original areas.

However, it is believed that if these commodities are provided for these communities it could discourage their nomadic and semi nomadic life cultures, and would result in the process of settlement of these communities. The pastoralists can be developed by ceasing their nomadic way of life, which is considered to be the first step to a higher stage of evolution (Carhill and Peart 2005). It could resolve the problems of overgrazing of pastures and desertification. The settlement of nomadic groups could relieve the pressures in settled areas such as towns and cities.

The settlement of nomads would involve a process of socio-cultural change, which would be accompanied with resistance from the older generation (UNDP 2001). The new community would find basic amenities at their home. Socioeconomic and cultural stability can be attained. The process would prevent both men and material losses, which are incurred due to drought and migration to adjacent places. New communities could contribute to the realisation of positive economic results, wellbeing of the community and resource productivity (Ben-Eli 2009).

3.3.6. Lack of food crops

The main problem for the future is food shortage because of the anticipated increase in the world's population to 8 billion people by 2025, and most of this increase is expected in developing countries which would rise to 4 billion by 2025 (McCalla 1994). Due to inadequate amounts of these agricultural commodities, it is believed that there would be possibility of an increase in the cases of hunger, malnutrition, low immunity and general diseases.

The situation could be worse in the communities living in and around the deserts, as these areas are characterised by limited supplies of agricultural commodities and livestock, commerce and industry. In the event of lack of food commodities their socio-economic stability is affected.

The depleted deserts and range-lands could be improved by rotational grazing, planting leaf forage trees, shrubs, grasses and following a silvi-pastoral system through community participation. Rain-fed, khushkaba, sailaba and hill torrents types of crop production systems could be used in these dry lands (Alam and Manzoor 2011).The cultivation of crops and trees could facilitate the supply of food and fodder and a sense of food security for the local population and animals (Drynet 2011).

An Agricultural Business Plan could be developed for creating a farm business plan that would provide a comprehensive outline on the nature of food and monetary crops and the scale of farming. This plan can be used to procure funds for an agricultural business venture and is customizable for your specific usage. The crops of: wheat, rice, millets and pulses Bajri (Pennistum Typhoideum), Guar (Cluster beans, Cyamopsis Psoralioides) and Til (Sesamum Indicum) are cultivable in these deserts, however the scale of cultivation is not up to the required level (Alam and Manzoor 2011).

3.3.7. Lack of sewage

The desert areas lack proper sewage and drainage systems. Neither natural drainage nor alternative sewage systems such as reed bed water sewerage system and drainage are used in the desert environment. In a reed and sewage system, a common reed such as Phragmites Australis can be used to transfer oxygen from its leaves, down through its stem (porous speta and rhizomes) and out via its root system into the rhizosphere (Hayat 2004), , as shown in Figures 3. 2 and 3.3.

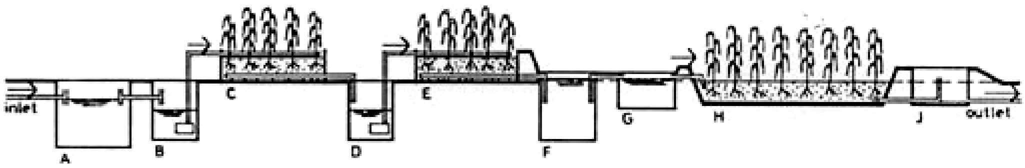


Figure 3.2. Flat site reed bed sewerage system (JSCL 2011)

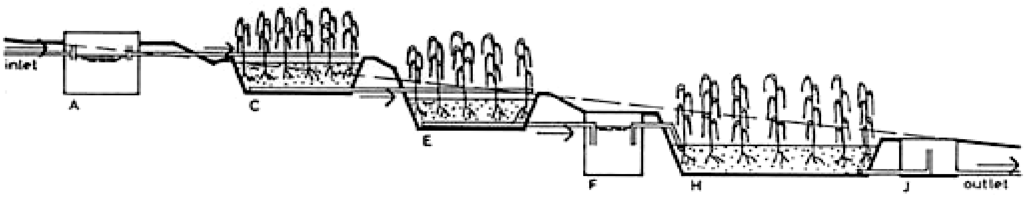


Figure 3.3. Sloping type weed bed sewerage system (JSCL 2011)

- A Existing Septic Tank
- B Pumping Station (if required.)
- C Vertical Reed Bed
- D Pumping Station
- E Vertical Reed Bed
- F Humus Tank
- G Balancing Tank
- H Horizontal Reed Bed
- J Flow Control Chamber

3.4. Desert communities and sustainable development processes

Since desert communities exist worldwide, initiatives were made by various quarters to bring about a sustainable development process, to improve their quality of life and to initiate the process of sustainable development. The international centre for living with the desert, Yazd is engaged in a renewed commitment for the development of desert communities (UNDP 2001). Interactive and survey techniques were also used in the past to assess indigenous and clean energy initiative programmes in the deserts (Beard 2003). These processes are reviewed below.

A project namely "Mount Desert Island Tomorrow" was initiated in 1987 to address concerns on seasonal growth and in stability of the year-round community (Beard 2003). The desert community project was aimed at linking components of a vibrant, healthy year-round community. The achievements of the Mount Desert Island Tomorrow project included the attraction of partners and funding sponsors for desert development projects and for learning tools for the local people to show how to engage with one another to resolve issues critical to the future of vibrant, healthy communities (Beard 2003).

An initiative on desert community development was made in 1992 in a new desert community called New Basaisa, 8 Km north of Ras Sudr in South Sinai, Egypt. In this project, small photovoltaic power units were used for the supply of electrical power generation to small workshops. Biogas, wind and solar water heating were used as energy sources (Arafa 1986). The initiative‘s objective was the construction of settlements "eco-desert communities" outside the overcrowded narrow Nile-Valley and Delta. The ultimate objective of the initiative was the resolution of the problems of lack of energy supply, education, waste disposal, sanitation and health issues in desert communities in Egypt. The Basaisa project demonstrated locally controlled development of desert communities and sustainable development processes (Arafa 1986).

The project Wadi Attir was developed as a model for sustainable development. It was based on community-based organic farming to combine Bedouin aspirations, values and experience in desert agriculture, with sustainability principles and cutting edge, appropriate, "green" technologies, including renewable energy production, resource recycling and arid land stewardship (Ben-Eli 2009). The project was the outcome of a collaborative effort of the Hura Municipal Council, the governing body of one of seven Bedouin towns in the Negev, and the Sustainability Laboratory, Israel. The objectives of raising goats and sheep, the production of organic meat and dairy products, the cultivation of a wide variety of medicinal plants, especially the production of highly nutritious, desert hardy, indigenous vegetables and the creation of a seed bank were used as tools for a sustainable development process in Wadi Attir (Ben-Eli 2009).

A desert development project was initiated in Thal, Pakistan. The project was aimed at reclaiming 20,000 hectares of a sandy desert area of sand dunes by the creation of shelterbelts, windbreaks and woodlots to stabilize dunes and protect the cropland and infrastructure. The project was affected by increasing access to irrigation water from canals, tube wells and traditional wells (UNEP 1998). Pakistan's Rangelands Research Institute and the local communities implemented this project, and the funds were provided by the Government of Pakistan and local farmers. The ultimate outcome of the project was community organisation through labour sharing, improved environment and poverty alleviation (UNEP 1998).

The Pakistan Council of Research in Water Resources carried out a research study on rainwater harvesting in the Cholistan desert, based on the development of catchments of capacities ranging between 3000 and 15000 m^3. According to Kahlown (2004), these pilot activities were used to harvest rainwater for the socio-economic uplift of the community. Furthermore according to Kahlown (2004), a pilot project of 92 rainwater harvesting systems was developed for the Cholistan desert, which included a storage reservoir, energy dissipater, silting basin, lined channel, and network of ditches in the watershed.

3.5. Fossil fuels energy scenario

Fossil fuels occupy the dominant share of the existing energy resources under current scenario. The current global fossil fuel consumption was around 507 Exa Joules in 2006, and an alarming increase in its consumption was recorded (EDRO 2009). However, fossil fuel has certain disadvantages. Fossil fuels such as oil, gas and coal, which provide almost 80% of the global energy demand, are responsible for environmental degradation poor quality of life, ecological imbalance and lack of biological diversity (Asif 2009).

Currently, 2.2 Giga tonnes of CO_2 per year are emitted presently as a result of the use of fossil fuels (Yuksel 2008). The situation in developing countries is quite complicated. For instance Pakistan's contribution to global emission levels is 0.38% and per capita CO_2 emissions are around 1900 kg, putting it in 133th place out of 186 countries in the world ranking of countries (WRI 2005). The main challenge to the global energy system is how to satisfy the energy needs in an environmentally sustainable manner. The World Energy Council scenario, which was a follow-up to the scenario work of the Global Energy Perspectives, which was produced in 1998 in connection with building new global energy scenarios up to the year 2050, believed that the carbon sequestration and separation technology has great potential for keeping CO_2 from entering the atmosphere (Schiffer 2008).

However, CO_2 sequestration processes have limited applications. Currently, four processes are used for carbon dioxide sequestration including; ocean sequestration, which involves either deep release of the gas, causing dissolution in water, mineral and biological sequestration involving the reaction of carbon dioxide with magnesium silicate, biological processes that lead to carbonates or methane and reforestation that contribute to sequestration as increased vegetation (Economides et al 2010). All these techniques have limited separation and sequestration potential, time constraints, considerable logistical problems and an additional cost burden (Backus 2010; Economides et al 2010).

The supplies of fossil fuels are also limited. It is anticipated that until 2020 no major increase in primary energy supply sources could be attained under the fossil fuels' system (Zerta et al 2008). In a moderate GDP scenario, it is projected that energy-demand growth would be 2.3 percent a year between 2010 and 2020, which is faster than the period from 2006 to 2010 (McKinsey 2008).

Under the fossil fuels energy scenario, a gap exists between energy demand and supply, and has developed multiple challenges to the modern way of living (Lloyd and Subbarao 2009). It is generally believed that fossil fuelled, thermal and hydro power generation systems are incapable of supplying electrical power and potable water adequately in the remote areas (AEDB 2010). The developing world that comprises over 50 of the poorest nations have no access to electricity, and the total number of individuals without electric power is estimated at about 1.5 billion (or a quarter of the world's population), concentrated mostly in Africa and Southern Asia (Gronewold 2009). Majority of the non urban areas have not been provided with electricity nor has agriculture been established over there.

These challenges vindicate a bleak fossil fuels energy scenario and underline the need to supplement energy needs with non-fossil fuels as well as underlying the need for a resolution of energy problems (MacKay 2008). Therefore, sustainable strategies are required for the exploration of sustainable energy sources that can equal the pace of an increasing population and a rapid rise in urbanisation. Major variations in the contemporary energy mix can bring sustainable energy and prosperity.

3.6. Possible solutions

The consequences of not recognizing the urgency of the productivity challenge could be disastrous, and could complicate further the energy situation in energy deficient solar-rich countries. The solution to this problem lies in the exploration of sustainable energy sources; therefore there is a need to look at new ways of meeting the water, food and electrical power needs of desert communities (Arafa 2011).

Effective use of indigenous energy sources can help in coping with these problems both in the present and in the future. Potable water, agricultural output and electrical power can be produced sustainably in these areas by the utilisation of solar power generation and desalination processes (Shah and Edwards 2011). By doing so the basic needs of potable water and electrical power can be fulfilled in an environmentally sustainable manner and considerable areas of barren desert land can be reclaimed by cultivation and.

3.7. Search for sustainable energy sources

Since fossil fuels are not sustainable forms of energy, and the energy produced from fossil fuels is inadequate, the search for sustainable energy sources is currently in progress (MacKay 2008). In order to achieve a sustainable global energy system, a profound transformation of the current energy structure is, therefore, essential. The question arises as to how these objectives can be attained.

It would be advisable that the goal of exploration of a clean and environmentally sustainable energy system should be established. Renewable energy sources can be used to achieve the objectives of clean energy generation and supply systems. It could resolve the problems of energy unavailability, anthropogenic emissions releases and the burden of environmental externality costs. Clean energy system would lead ultimately to the process of sustainable development in and around these deserts in the long run (Shah and Zhang 2011).

It would also facilitate the processes of diminishing the dominant share of fossil fuels. It is high time that the negative impacts of unsustainable energy sources are realised and the avenues of renewable energy sources are explored in light of their existing potential.

3.7.1. Role of renewable energy sources

The rapidly increasing global energy needs can be met by the use of renewable energy systems without endangering the life of generations of humans without irreparable environmental damage to ecosystems. Renewable energy sources such as biomass, wind, solar, hydropower, and geothermals are sustainable energy sources, as these are abundant and are capable of meeting energy services in an environmentally friendly manner (Herzog et al 2000). In 2009, the total world energy supply and consumption was 8352.77 Mtoe, which was equivalent to 349 Exa Joules. The share of renewable energy was 2792.88 Mtoe, which was equivalent to 116 Exa Joules (IEA 2011).

The share of renewable energy sources in a primary energy supply has been increasing gradually. The renewables supplied 17% of the world's primary energy needs in 2007, which was 160 GW. Installed capacity worldwide for all power generation in 2004, including large hydropower (6%) and other renewables (9%), such as solar, wind, modern biomass, geothermal and bio fuels was 3800 GW (Yuksel 2008). The success of renewable energy can be realised from the continual increase in its share worldwide. According to Renewable global status report (2010), the renewable capacity continued to grow at rates close to those in previous years, including grid-connected solar PV (53%), wind power (32%), solar hot water/heating (21%), geothermal power (4%), and hydropower (3%). The share of renewable energy in power generation has also increased. Furthermore according to renewable global status report (2010), the renewable power capacity worldwide in 2011 reached 1,320 gigawatts in 2010, up almost 8% from 2009.

It is believed that there are problems of intermittency, space and costs with a few of the renewable energy sources. However, these problems are manageable by the proper selection of a renewable energy source. The problem of intermittency occurs when the energy is not continually supplied at the required rate in periods when the input from highly intermittent renewable energy sources becomes zero.

Wind power, by its nature is more variable or intermittent; therefore connection to an electricity grid system or other electricity producing energy systems from conventional generating stations through diesel generators to other renewable energy systems is required to meet energy needs around the clock (SERPTM 2000). Also the amount of wind power generation is not controlled by demand, but by the prevalent wind speed and is not considered dependable for the base-load of any grid (Baig 2011).

The solar thermal systems can resolve this problem to a considerable extent in comparison to other renewables sources if a larger storage system is integrated. A solar thermal system can be enabled to meet the total electricity demand from solar thermal storage over a four day period in the event of little sun, provided the storage capacity is designed 24 times as great as would be necessary to enable the solar thermal component to operate continuously for 24 hours (Trainer 2010). Therefore, solar power generation systems could be able to plug gaps left by other renewable sources and guarantee electricity supply in winter from a wholly renewable system, even in highly favourable solar regions.

3.8. Viability of solar energy

Of all the renewable energy sources, the potential of solar energy is remarkable worldwide. These prospects are brighter especially in solar-rich countries. It is anticipated that the total energy needs of people living in solar-rich countries can be met adequately with the utilisation of solar energy. However, solar energy has a very low density; therefore for large scale production of electrical power, a larger area of the land is required, in comparison to the area required for fossil fuelled plants. The land problem can be resolved by the use of low opportunity costs desert land for large scale power generation (Meisen and Pochart 2006).

Solar energy based electrical power generation is more efficient than electrical power generated from fossil fuels, because fossil-fuel energy to electricity conversion efficiency is 40%, which is less in comparison to the Rankine cycle, which operates solar power conversion efficiencies that go beyond 40% (MacKay 2008).Various solar power generation processes technologies are used. According to the renewable solar energy report (2012), presently, solar panels, concentrated solar power plants, updraft solar towers and concentrated photovoltaic and portable solar technologies are successfully used for large scale power generation. Solar panels are considered the most popular method of electric current generation that uses the technique of photovoltaic panels. Furthermore according to the solar renewable energy report (2012), a concentrated solar thermal generation process is helpful in increasing the overall efficiency of the plant.

Photosynthetic, photo electro-chemical, thermal, and thermo chemical processes are used for the conversion of solar energy into chemical energy, which is then stored in the form of chemical fuels such as hydrogen (GCEP 2006). Diversification in solar energy technologies has resulted in the development of solar mobile products. According to the solar energy report (2012), portable solar technologies such as solar chargers, solar travellers hand bags and mobile solar kits are some important inventions of this century.

Both thermal and photovoltaic methods of solar energy utilisation can be used for large scale power generation in the solar-rich countries. However, concentrating solar photovoltaic power generation systems are favoured over thermal systems on account of increasing the efficiency of the cells, high efficiency, low system cost and a low capital investment as well as use of less expensive semiconducting PV material to achieve a specified electrical output (Solaries 2011). PV cells in a CPV system can be built into concentrating collectors by using a lens or mirrors to focus the sunlight onto the cells.

According to Hertog and Luciani (2009), due to the increase in installed capacity of solar energy utilisation projects, the standard of living has been raised considerably in developing countries. The leading examples in Asian economies are UAE, Qatar, Bahrain, Kuwait and Oman. Furthermore according to Hertog and Luciani (2009), the publicly owned Mubadala Development Company, which was founded in 2006 in Abu Dhabi, has been engaged in the implementation of solar power generation and desalination projects. Solar powered environmentally sustainable processes are launched on a large scale in the UAE. Masdar city, which is 6.5 km^2 is a 'carbon-free' area with a population of 90,000 and was developed as a hub of environmentally sustainable energy (Masdar 2011). Solar powered power generation and desalination projects were also launched in neighbouring countries of the UAE in the Gulf. The first Gulf-based clean development mechanism project, an oilfield gas recovery and utilization venture, that prevent flaring of natural gas at the Al-Shaheen field was established in May 2007 in Qatar. Also a QIA-sponsored £250 million Qatari-British fund was created in November 2008 to promote clean energy technologies and research and for lowering carbon dioxide levels in the country.

Therefore, solar energy seems to be a viable option for solar-rich countries (Raja et al 1999). Desert resources such as high radiation solar energy and underground aquifer brackish water can be exploited in a sustainable manner to address the problems of lack of potable water, electrical power, dryness and land infertility (Harijan et al 2007; Zaigham 2001). Solar power plants are also believed to be crucial in addressing the threat of climate change and for new economic growth.

3.8.1. Prospects of solar energy utilisation in the deserts

As mentioned, huge solar power potential exists in the deserts in solar-rich countries, which can be used for meeting electrical energy needs of the communities living in and around the deserts. It is estimated that just 4% of the total world desert area is capable of producing the total electrical energy needs of the world (Meisen and Pochart 2006; Loster 2010). The estimated solar potential in world regions is illustrated in Figure 3.4.

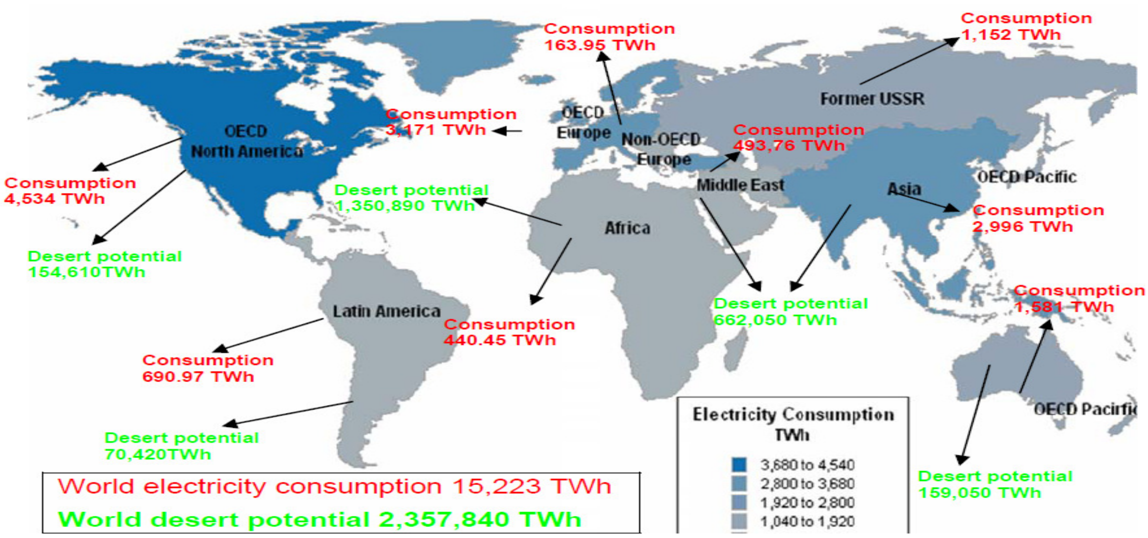


Figure 3.4. Estimated desert solar potential in various parts of the World (Meisen and Pochart 2006)

According to MacKay (2008), the solar cell manufacturer Amonix believes that concentrating solar power could produce an average power per unit of land area of 18W/m^2, and a 250 kWh power from roughly two of 15m×15m solar concentrated collectors' area. Furthermore according to MacKay (2008), it was estimated that the world's total power consumption, which was 15,000GW in 2008 could have be produced by a 1000 km by 1000 km square in the Sahara desert land area. A schematic of a large scale photovoltaic system is illustrated in Figure 3.5.

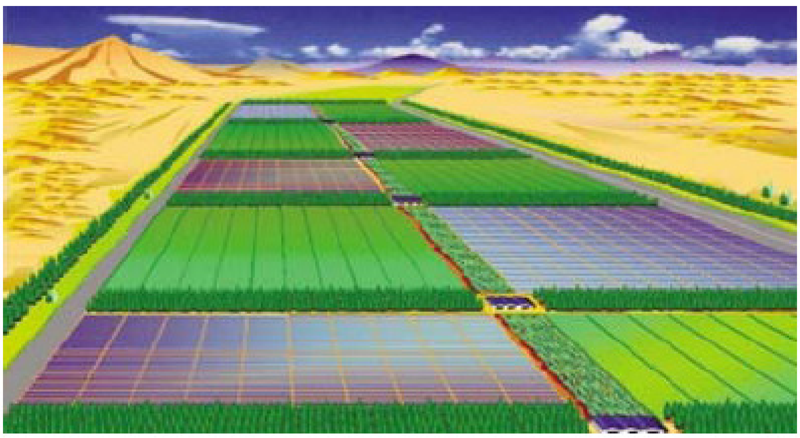


Figure 3.5. A schematic of large scale phototvoltaic systems in desert area (Meisen and Pochart 2006)

It is established that the process of large scale solar power generation could facilitate the process of self-contained and environmentally sustainable energy generation and supply systems in the isolated places.

3.9. Energy scenario in Pakistan

The energy scenario in Pakistan is characterised by the dominant share of fossil fuels in the domestic, commercial and industrial sectors. There are problems of energy scarcity and the release of anthropogenic emissions due to dominant use of fossil fuels in domestic, commercial and industrial sectors. The amount of greenhouse emissions in Pakistan, in the year 2005, was estimated at 243.1 mega tonnes, which was provided in a list of countries ranked by total greenhouse-gas emissions (WRI 2005). The listing was based on data for carbon dioxide, methane, nitrous oxide, per fluorocarbon, hydro fluorocarbon, and sulfur hexafluoride emissions.

The energy supply situation is poor in the villages and deserts because of the remoteness of these areas from the power generation centres (AEDB 2010). According to Asif (2009), there is substantial potential for renewable energy sources in the country for managing the current energy crises. Furthermore according to Asif (2009), diversification of the energy supply mix and the utilisation of renewable energy resources should be the core of the future energy strategies, so as to enhance energy security in the country.

3.9.1. Fuel mix, generation fuel mix, nationalised and ageing of power stations

The current energy mix in Pakistan seems to be inadequate, imbalanced and environmentally unsustainable. According to Harijan et al (2007), the primary commercial energy supply in Pakistan was 60.4 MTOE in 2006-07, with the fossil fuels share being 86.4% and the indigenous recoverable reserves of oil and gas were 47.4 MTOE and 605.4 MTOE respectively.

Depletion process of gas and oil reserves has reached to peak levels. According to Baig (2011), the gas reserves in the country are diminishing over time, and no new reserves have been discovered. Electrical power shortages are also common. According to Baig (2011), about one third of Pakistan's total electricity is generated by hydro plants located on a single river, the Indus, with the result being when there is a shortage of water in this river, which is frequent in the winter season, the production from the hydroelectric plants drops to less than half the installed capacity.

Electric power generation, transmission and distribution have been looked after in Pakistan by a public sector organization-the Water and Power Development Authority (WAPDA) since 1947. According to Baig (2011), the Pakistan Electric Power Company (PEPCO), which started looking after the thermal power generation function of WAPDA since 2005, operates currently 12 thermal power plants with a total installed capacity of 4,900 MW and these plants are more or less fifty years old. The private sector invested in the generation of electricity during the period from 1993-2001, having the capacity of 100 to 1500 MW. There are 15 International Power Producers (IPPs) having a total installed capacity of 5,822 MW (Baig 2011).

The intensity of power shortages is increased to alarming levels. The main reasons for the power shortages are inadequate generation capacity, low water flow in rivers, depleting natural gas reserves, poor maintenance activities and high oil prices. According to Baig (2011), existing power plants operate without scheduled maintenance, which has reduced the operational performance of the existing power plants and their capability to supply power to the grid. Because of these problems there are considerable shortfalls in the demand and supply of electricity. Furthermore according to Baig (2011), the demand from the domestic consumers is low in winter being between a few hundred to three thousand mega watts in comparison to the summer when the difference between demand and generation rises to about six thousand megawatts.

3.9.2. Demographical facts of Pakistan

Pakistan is an overpopulated country and there is a growing demand for energy. The population of Pakistan in 2010 was 173.5 million (MOPGOP 2012). The total population of the deserts areas is estimated as 3.84 million. The population of Thar Desert is in the ranges of 0.85 to 0.95 million people (Zaigham 2001). The human population in the Cholistan desert is about 0.11 million while the livestock population is nearly 2.0 million (Kahlown 2004). The population in the Thal desert is 2.5 million (UNEP 1998). The population in Kharan is estimated at 0.28 million people (IUCN 1992). The population is scattered round different places according to the availability of drinking water. Socio-demographic variations exist within these populations in relation to the barriers faced in terms of utilization of services.

Due to non utilisation of indigenous renewable, the energy sources utilisation, energy needs of the domestic, commercial and industrial sector could not have met adequately. The problem of low energy per capita consumption in the rural and desert areas has resulted in poor lifestyles. The majority of the population lives without access to health or sanitation facilities (Siddiqui et al 2004). According to Hussain (2004), in Pakistan, the National Poverty Line, which was developed on the basis of 9839 Joules per adult equivalent per day for the year 2000-01, was estimated as Rs 748.57 per capita per month at the prices of 2000-01. Furthermore according to Hussain (2004), the poverty line at the prices of 2004 was estimated at Rs 848.798 per adult equivalent per month.

3.9.3. Geographical dimensions of Pakistan

Quite large arid and semi arid land areas exist in Pakistan. According to Alam and Manzoor (2011), the arid land constitutes about 88 per cent of the country's total geographic area of 79.61 Mha. The land is used in Pakistan for agriculture, livestock production, and forestry. Furthermore according to Alam and Manzoor (2011), 26.5% (16.65 Mha) of the total land is irrigated and is used for agriculture, including 5 Mha of cultivated land, which is semi arid and rainfed. More than half of the land area is occupied by the arid and semi arid regions. Also according to Alam and Manzoor (2011), about 68.61 Mha of Pakistan falls under arid and semi arid areas including 41 Mha arid areas and 27.61 Mha semi-arid areas. The highest share of semi arid land is occupied by the rangelands. According to Noor (1989), around 53% of the total area and 61.9% of the arid and semi arid land (42.5 Mha) are rangelands, which are located on rocky soils, deserts, and rough topography, and receive less than 200 mm rainfall. Productivity is very low and it is not possible to utilize these rangelands for sustained farming purposes. Furthermore according to Noor (1989), these rangelands partly support 93.5 million livestock during the summer.

Currently, the arid and semi arid desert land (29.41 Mha) in Pakistan makes little contribution towards the current energy generation. However, it is believed that considerable areas of desert in Pakistan can be used for a process of sustainable energy generation and agricultural cultivation (Rasool, 2010; Shah and Zhang 2010).According to Kahlown (2004) there are four deserts in Pakistan; the largest of these deserts is Thar with an area of 4.3 Mha, followed by Cholistan having a total area of 2.6 Mha, Thal with 2.3 Mha and Kharan having an area of 1.8 Mha.

3.10. Life style differences in urban, rural and desert communities in Pakistan

Pakistan is a developing country. It has low energy consumption levels, a low standard of living and high population growth (Ilyas 2006). According to some estimates, about 70% of the population in Pakistan lives in rural areas. The energy requirements for lighting and cooking are met by different types of fuels in rural, desert and urban communities. Since there are marked differences in the lifestyles of urban, rural and desert communities, the ratios of the communities living at subsistence level and above subsistence level in the cities and towns varies, as is shown in Figure 3.6.

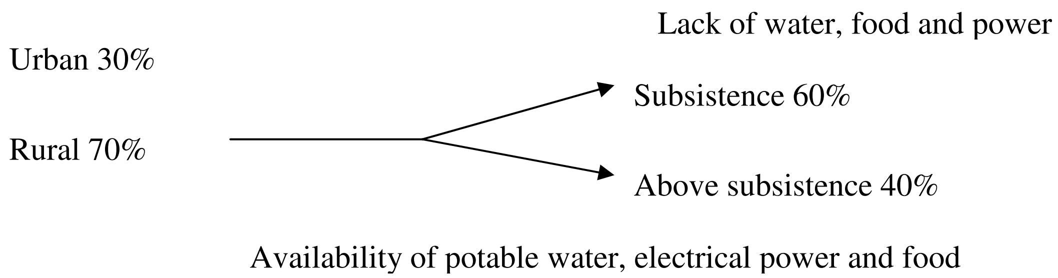


Figure 3.6. Population of **c**ommunities at subsistence and above subsistence levels

The per capita electrical power consumption in Pakistan in 2004-05 was 425 kWh (Asif 2009). The electrical power consumption per annum in the rural areas and the desert areas is lower than 425 kWh. Only 16% of rural people have grid-connected electricity, compared with 85% of the urban population (Ghaffar 1994). It is believed that in urban areas, the basic daily energy consumption of a low-income household is in the range of 1.16–1.33 kWh and is 0.83 kWh or less in rural areas (Barnes and Floor 1996)

The household sector is the fastest-growing energy consuming sector in the country. According to Qureshi (2007), 54% of the total final energy consumption in Pakistan is used by the household sector. Use of biofuels is dominant in rural areas. A considerable portion of biofuels is used in these areas. Furthermore according to Qureshi (2007), 90% of the rural and 50%of the urban population use biomass fuels. Firewood and dung are used for lighting and cooking in the rural and desert communities.

Rural and desert populations in Pakistan have limited access to electricity. According to Ghaffar (1994), only 16% of rural people have grid-connected electricity, compared with 85% of the urban population. In urban areas, natural gas is used mainly for cooking and heating, and accounts for about 50% of the total modern fuel consumption in the residential sector. Electricity is used mainly for lighting and space cooling in urban areas and kerosene, wood and biofuels are used for cooking and for lighting in the non urban areas (Qureshi 2007).

3.11. Prospects of solar energy utilisation in the deserts of Pakistan

The climate in the deserts remains hot for most of the year. The temperature is quite high in summer especially in the months of May, June July and August every year due to the location of the country in the temperate zone above the tropic of Cancer. The tropic of cancer forms the boundary between the Torrid and North Temperate zones. It is a parallel of latitude about 23 degrees north of the equator, which marks the most northern point where the sun can shine directly overhead. The average temperature from May to August reaches to 50^0 C in most of the cities in the centre, south and west, excluding the extreme north of Pakistan (Harijan et al 2007).

The agricultural output is not adequate in the deserts' lands due to the problems of lack of irrigated water, lack of utilisation of underground aquifer water facilities, water logging and salinity in the farm lands (Choudhri and Soomro 2009). The deserts in Pakistan are characterised by dryness and drought. The recent drought remained in Kharan, Thar and Cholistan from winter 1999 extending to early summer 2000 (Palijo 2011).

To resolve these problems and meet the energy challenges of desert communities, it is essential to launch a large scale solar powered generation process in the Pakistani deserts. It is believed that the energy scarcity problem could be resolved to considerable extent by the utilization of the solar energy potential in the Thar, Thal, Cholistan and Kharan deserts in an environmentally sustainable manner (Rasool 2010). It is open fact that these deserts in Pakistan are replete with energy sources such as high radiation solar energy and land spaces (AEDB 2010). The map of these deserts, edited by the author is given in Figure.3.7.

Figure.3.7. Map of Pakistan showing Thar, Thal, Cholistan and Thal deserts (MOW 2011)

The Thar Desert in Pakistan can be used as a test case for the assessment of the capability of solar potential for meeting the energy needs of the communities living in and around these deserts. It could prove a sustainable energy source, and can also initiate the process of sustainable development in all sectors of the economy (Shah and Edwards 2011).

The Thar Desert is also home to 75 billion tonnes of lignite coal reserves (Siddiqui 2007). However, coal is an unsustainable fuel because of the subsequent release of anthropogenic emissions in power generation. Carbon separation and sequestration processes could be applied to mitigate the problem of carbon dioxide emissions. However, additional costs would be required for the integration of these processes in the power generation. Therefore it is suggested that the indigenous coal can be used as a source to generate revenues, which can be used to finance the costs of solar power generation. Oil exporting countries in the Gulf region are engaged in such practice and are successful considerably in their efforts to switch over from fossil fuels to solar and wind energy projects (Masdar 2011).

Considerable advances are made in the efficiencies of solar photovoltaics. Efficiency ranges varies according the nature of materials used in the cells. Ultra high-efficiency phototvoltaic systems that use multijunction tandem cells and semiconductors such as GaAs and GaInP2 are 30% efficient cells and solar photovoltaics systems that use single-crystal silicon materials are 19% efficient (Deb 2000). The highest energy conversion efficiency of crystalline silicon PV cells is 23.5 (Franzen 2012). Dye-sensitized nanostructure TiO_2 solar cells are 11%-20% efficient (Deb 2000). These efficiencies are verified by the National Renewable Energy Laboratory (Franzen 2012)

The potential maximum and minimum solar yields are calculated on the basis of the highest conversion efficiency 25% and minimum solar conversion efficiency of 11%. These yields are calculated on the basis of solar radiation levels in Pakistan (AEDB, 2010). Minimum and maximum solar efficiencies achievable are used to calculate minimum and maximum power yield (Saga 201; Deb 2000). The results attained so far are promising. The maximum and minimum electrical power yield capacities that can be produced in these deserts over the utilisation of 1/100 part of the total desert areas are illustrated in Table 3.1.

Table 3.1 Calculation of maximum and minimum power yield per day (GW/m^2) that can be obtained over 1/100 desert land area at Thar, Cholistan, Kharan and Thal deserts, assuming maximum and minimum solar conversion efficiencies of 23.5% and 11%, and available solar radiation of 1000 W/m^2 per day (Franzen 2012; Saga 2010; AEDB 2010; Deb 2000).

Desert names	Total desert land area (km^2)	Maximum power yield per day (GW/m^2)	Minimum power yield per day (GW/m^2)
Thar	43,000	101.50	47.30
Cholistan	26,000	61.10	28.60
Thal	23,000	54.05	25.30
Kharan	18000	42.30	19.80

It is believed that the efficiency of solar cells decreases consistently with increasing environmental temperature. However discrepancies exist between theory and experiment and it has been found that by improving the bonding of wires to the solar cell increased currents could be used in the cell without the risk of melting the bond wires, which can enable to push the cells into the radiative regime at high voltages (Guenette 2006).

A concept solar wall (phototvoltaic and solar thermal hybrid system is developed recently to reduce the operating temperatures of the PV module and to improve electrical performance for only a 20% additional cost. In this process PV modules are mounted slightly above the solar wall surface to allow air to be drawn in the modules to produce the cooling effect, which can remove heat energy by the super wall and can increase PV efficiency by up to 10% (Solarwall 2010). The heat energy captured from the solar phototvoltaic can be used for the displacement of traditional heating fuel in the building or space. The solar wall phototvoltaic thermal hybrid system can deliver 300-400 Watts/m^2 more energy in comparison to a conventional phototvoltaic system that produces 100 Watts/m^2 (Solar wall 2010).

3.12. Review of solar technologies

As discussed in the preceding section, solar energy technologies can provide alternative energy sources to fossil fuels. The assessment of available renewable technologies leads to the use of solar energy as a reliable substitute to fossil fuels, on account of its capability to meet energy needs in present and in future in an environmentally sustainable manner (Pimentel et al 1994).

In order to make use of the most efficient and economical solar technology it is essential to choose an effective solar technology for utilisation of the available potential. A combined strategy of using solar technologies consistent with the characteristics of different geographic regions could be developed (Pimentel et al 1994). The available solar technologies are, therefore, reviewed to find their suitability in various environments.

The land area varies considerably in photovoltaic and thermal power generation processes. According to Bosatra et al (2010), a typical utility scale photovoltaics plant of a ground fixed type that uses crystalline-silicon PV modules uses 50-55% less area than the area of a CSP plant of the same power capacity. The position of solar photovoltaics panels can be either flat or slopped Furthermore according to Bosatra et al (2010), the fabrication of a solar phototovoltaic plant is generally easier than that of a CSP plant, as it needs flat land in comparison to photovoltaic plant, which can easily be installed in sloped territory. Therefore, phototvoltaic plants are more convenient to expand than the solar thermal ones. The installation times of solar photovoltaics plant is also less than the thermal plant. According to Bosatra et al (2010), PV plants are built in a shorter time than CSP Plants, the time required for the installation of a 50 MW Utility-Scale PV Plant is about 14 to16 months in comparison with that of a 50 MW CSP, which takes 24 to 36 months.

However, in certain cases the solar thermal plants have advantages over the photovoltaic plants. According to Bosatra et al (2010), PV plants are not suitable for the supply of predictable energy to a network, unless control features such as inverters, frequency and voltage response capability and battery storage systems are designed and integrated within it, which incurs an addition to capital costs. Concentrating solar phototovoltaic power plants generation is highly predictable because it is coupled with thermal storage that facilitates the management of load and demand curve per hour per day and it also covers peak hour’s demand. Primary and secondary control systems are integrated in solar thermal systems. CSP plants are equipped with primary and secondary grid frequency control to support grid exploitation during steady state and transient conditions (Zhang and Osborn 2007).

However, concentrated solar photovoltaic systems could give better results than the thermal solar systems. Because of the requirement of intermediate medium components in thermal power generation and the involvement of construction, operation and maintenance costs, solar photovoltaic power generation processes are preferred (Quasching 20010). Therefore, the phototvoltaic option could give better results, as it is free from intermediate systems and related costs. A brief description of solar technologies is given in the following sections.

3.12.1. Solar thermal technology

Solar thermal power generation technologies are used successfully worldwide power generation. In solar thermal power systems, solar energy is converted into heat energy by absorbing it through solar collectors, which is transported through the mediums of water, air, and other fluids, and it uses storage systems to overcome the mismatch between energy available and power delivered (Quaschning 2001). There are various types of solar thermal power equipments such as a parabolic trough, solar power tower, solar dish and solar chimney. The principle of a parabolic trough solar collector is shown in Figure 3.8.

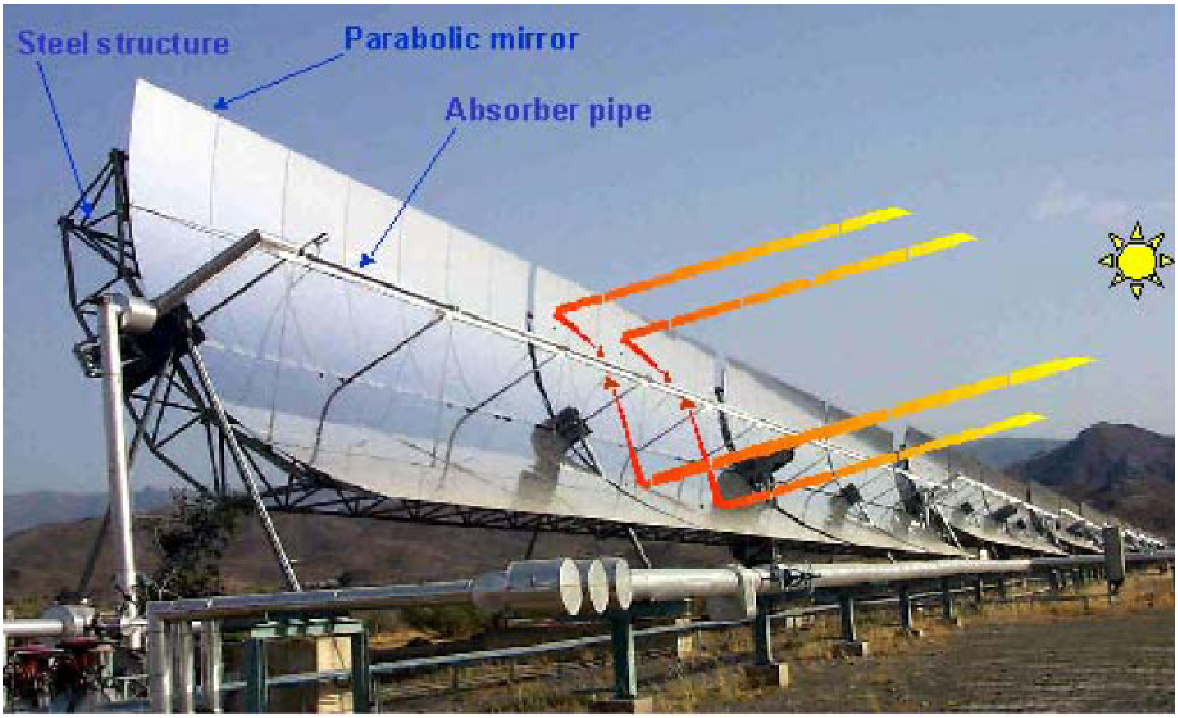


Figure 3.8. Principle of the parabolic trough solar collector (Quaschning 2001)

A few of the solar thermal processes are oriented to the desert environments such as solar dishes and solar chimneys. The power generation capability of these technologies is well demonstrated. The Dish solar Stirling solar power systems are successful in Spain, the Mediterranean region, and Australia in terms of inherently high overall system efficiency in converting sunlight to grid-quality electricity and the attendant potential for lowest cost solar electricity (Zhang and Osborn 2007).

Solar chimneys are used successfully in the desert environments. According to (Papageorgiou (2008), because of its power generation capability in strong winds or sand storms without requiring water, it is suitable for the proposed desert sites. There are bright future prospects for the use of solar chimneys in the desert. According to Papageorgiou (2008), it is anticipated that floating solar chimney technology has the potential to produce 50% of the world's electricity demand over a 2-3 of the existing desert or semi-desert land area, operating on 1% efficiency.

Capital costs of solar equipments are recoverable in a short span on account of the small payback periods. According to Smil (2006), it is estimated that 60,000 kWh of energy can be generated by each solar chimney unit in a year. If this price range is compared with the power output, the kWh price can be calculated. The kWh capital cost can be calculated on the basis of total cost and total power output in kWh. According to Smil (2006), per kWh capital cost of solar equipment lies in the range of $2.5-1.2.

3.12.2. Solar photovoltaic technology

In this process semiconductor materials such as silicon are used in photovoltaic solar cells. The incoming photons separate positive and negative charge carriers that produce an electrical voltage and the electrical current can drive a load. An inverter converts DC voltage to AC and feeds the solar power into the grid, as shown in Figure 3.9.

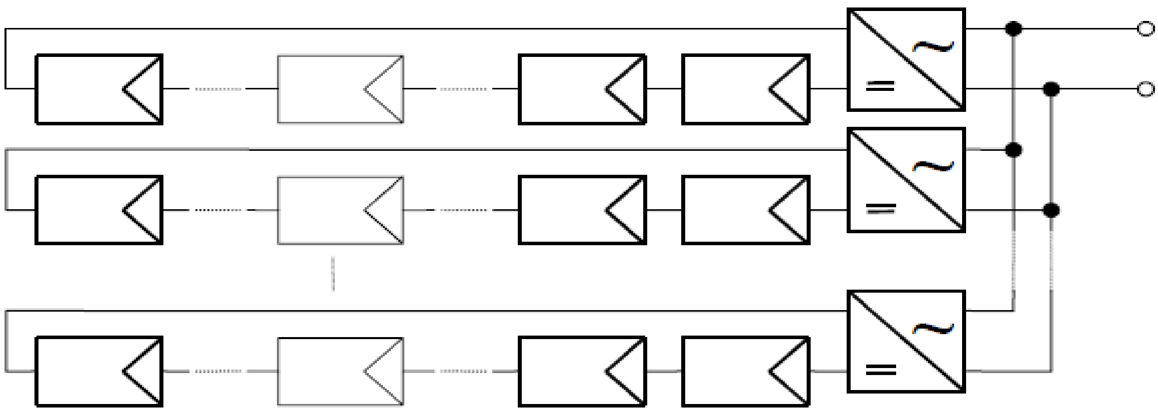


Figure 3.9. Photovoltaic modules and inverters build up in a phototvoltaic system (Quaschning 2001).

Uninterrupted supply of solar cells raw material would be required for a phototovoltaic power generation process facility. However, it is believed that shortage of raw material for the solar cells could inhibit the process of large scale production of solar cells. According to Meisen and Pochart (2006), silicon feedstock shortage could hinder the process of utilisation of large scale solar phototovoltaic power generation, as the total demand of polysilicon in 2005 was 2,825 tonnes while the supply was only 130 tons because of the higher PV growth (50%) per year.

However, alternative solar cell materials and processes are developed to cope with the problems of polysilicon shortage. Thin film solar cells, self assembling solar cells and ultrafast laser scribing technology are few of them. The thin film amorphous, non crystalline, cells occupy less space than the thick solar cells, and are deposited in very thin, consecutive layers of atoms, molecules, or ions using much less material. According to Meisen and Pochart (2006), since thin cells use much less material, the cell active area is reduced to only 1 to 10 micrometers thick in comparison to thick films, which are 100 to 300 micrometers thick, so the total cost of the solar electrical system is reduced. The cost difference is due to the use of non-silicon material such as copper Indium Gallium diSelenide and the use of low cost substrate.

The thin film PV cells are more economical than thick solar cells because they use much less semiconductor material than the crystalline silicon cells. The thin film solar cells can deliver more energy more than thick silicon cells at low cost and has also large production volume advantages (Meisen and Pochart 2006).

The share of thin solar cells is increasing gradually. Thin-film solar cells accounted for about 20% of the photovoltaic market globally in terms of watts generated in 2006, and is likely to hold nearly 31% of the market share by 2013 (EBD 2011). The particular feature of this technology is the use of organic materials, which consists of small carbon containing molecules, as opposed to the conventional inorganic, silicon-based materials (Meisen and Pochart 2006).

3.13. Solar photovoltaic system's component costs

Solar PV system costs include module, inverter, installation, solar cell, electrical materials and packaging costs. Half of the cost of PV power is incurred when manufacturing the modules. The remaining half of the cost elements are the cost of mounting the hardware and the electrical components such as inverters, and the labour costs for installation of the solar system. The National Renewable Energy Laboratory cost breakup is illustrated in Figure 3.10.

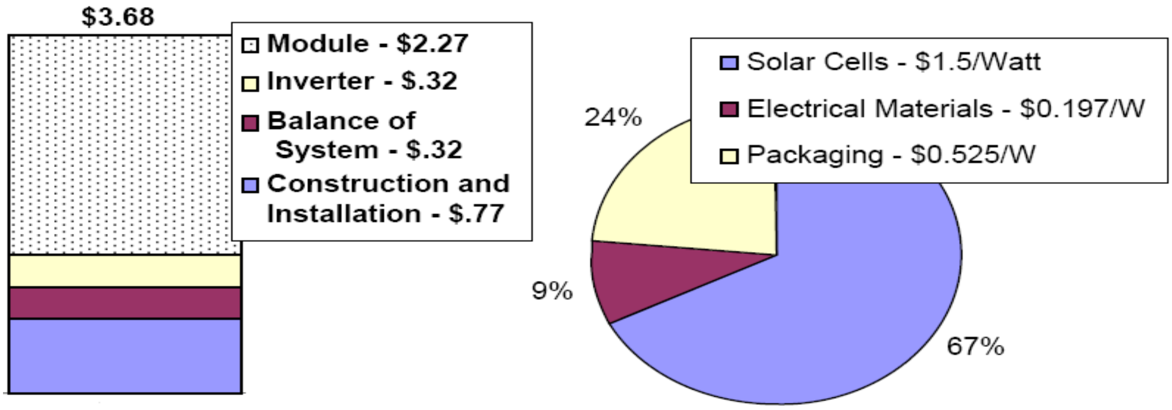


Figure 3.10. Solar PV system and module manufacturing cost breakup

All those components add up to a typical "installed cost" of around $6 or more per Watt today, of which roughly $2.50 is the cost of purchasing PV modules (Meisen and Pochart 2006). The cost can be optimised by the use of a low cost manufacturing process and the less expensive raw materials become.

The emission mitigation costs are negligible with this mode of power generation. Solar phototovoltaic have close to zero carbon emissions in comparison to carbon emissions releases from fossil fuels. According to GCEP based energy assessment analysis (2006), it is estimated that a 1kW PV panel would give a yearly CO_2 savings of 1.33 $x10^3$ kg on an average sunlight of 5.5 hours of per day, and the payback period of solar cells is small. Furthermore according to GCEP based energy assessment analysis (2006), a 12% solar efficient panel releases $3.3x10^3$ kg of CO_2 for the generation of a 1kW power, which is paid back within a time scale of 2.5 years in the form of avoided emissions of $1.33x10^3$ kg/year. The CO_2 payback period can be reduced further for higher cell efficiencies solar cells.

It is thought that low labour costs, low material costs, award of subsidies and incentives can reduce further the total solar cell production costs. For instance, the labour cost in China is less than $200/month per worker and sales, general administration, research & development, peripheral costs, and tax rates are lower (Meisen and Pochart 2006). The labour intensive solar technologies are used in China to gain a competitive edge worldwide, besides the use of smart-price domestic-made equipments in comparison to capital-intensive automated assembly equipment.

In China low cost and high grade scrap poly silicon material is used in the manufacture of solar cells, which is available at a price of $150-170/kg and at $50-$70/kg, and this material is used instead of high spot virgin poly silicon material, which is available at higher prices such as $200/kg (Meisen and Pochart 2006). Low cost material and labour intensive technologies can also be used for gaining the edge in power generation in the solar-rich and energy deficient developing countries.

Further solar capital costs reductions are expected in future, for instance it is anticipated that the PV electricity would be more economical than fossil-fuelled electricity in the year 2025 (Solarbuzz 2010). The worldwide downward trend in solar prices has also affected the solar equipments costs in Pakistan. There has been a 50% decrease in the price of solar panels over the course of the past year, however, there has not been a substantial increase in sales due to lack of awareness among the people regarding the benefits of the use of solar power. According to Baloch (2011), solar power currently costs an average of approximately Pak Rs 21.75 per kilowatt-hour, in comparison to the oil-fuelled power plants, which produces power for about Pak Rs 18 per unit (Baloch 2011). Solar electricity prices have become competitive in Pakistan. Furthermore according to Baloch (2011), solar powered electricity is far cheaper than the diesel generators used in industrial units, which is Pak Rs 32 per unit. Solar energy capital costs could be further reduced if indigenous solar cell manufacturing facilities are established in various parts of Pakistan (Shinwari et al 2004).

The use of single element and organic semiconductor film technologies, which consume less material could further lower costs on account of lower cost production methods and a higher output. Economies of scale of production of solar cells and technology step change can also be used as a means for costs' optimisation of solar cells.

3.14. Health, safety and environmental issues associated with solar product lifecycle of photovoltaics

There are potential environmental, healths and safety hazards associated with the full product life cycle of photovoltaics, including the solar cell materials, production processes, installation, decommissioning and dismantling of the solar power plant.

Solar cells account for only a small fraction of the total materials (4% of the mass of a finished module), because the outer glass cover constitutes the largest share of the total mass of a finished crystalline photovoltaic module (approximately 65%), followed by the aluminium frame (20%), the ethylene vinyl acetate encapsulant (7.5%), the polyvinyl fluoride substrate (2.5%) and the junction box (1%) (Oregon 2011). A schematic diagram of the solar phototvoltaic panel is given in Figure 3.11.

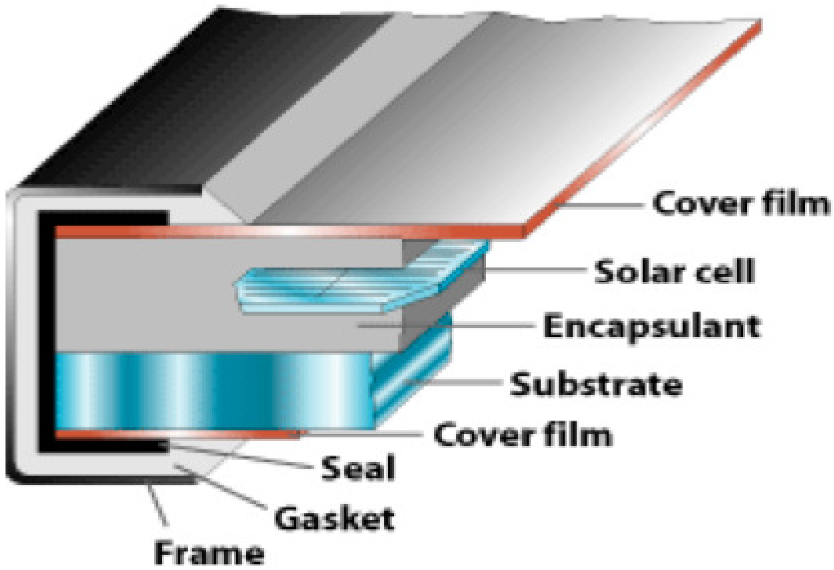


Figure 3.11. Diagram of solar phototvoltaic panel (Oregon 2011)

Potentially harmful materials can be released into the environment especially in crystalline solar modules from lead containing solders, which lead to leaching into landfill soils and eventually into water bodies (Oregon 2011). The major safety and environmental issues related to the manufacture of photovoltaics are the safe handling of gases used for surface treatment or the growth of thin films such as AsH_3, SiH_4, GeH_4, PH_3, $B2H_6$, and H_2Se), and the toxicity of some semiconductor components such as Cd (GCEP 2006). However, it is believed that the replacement of toxic components can eliminate most of the concerns about the environmental risks of photovoltaics.

However, care should be taken regarding the safe disposal of these materials and especially lead solders. Small quantities of valuable metals such as cover glass, aluminium frame, solar cells copper and steel present no hazards, as these are recoverable, although this excludes the ethylene vinyl acetate encapsulant and polyvinyl fluoride substrate. However, the ethylene vinyl acetate can be removed through a thermal process using strict emission controls and the by ash land-filling (Oregon 2011).

3.14.1. Risks and hazard assessment of solar photovoltaics power plants and their mitigation measures

A risk assessment process is used to study the hazards and risks associated with the solar power generation and desalination plants, and to make use of safety checks that precludes the possibility of an interruption to the processes, or loss of men, materials and damage to the environment. The risks associated with the installation, decommissioning and disposal of photovoltaic power plants can be identified. The advantages that could be accrued by the implementation of a health, safety and environment measures are analysed.

These measures would control risks, and ensure the protection of men, materials and assets. A risk assessment process diagram has been developed by the School of Photovoltaic and Renewable Energy Engineering for a solar photovoltaic processes, as shown in Figure 3.12 and can be applied to neutralise health, safety and environmental effects.

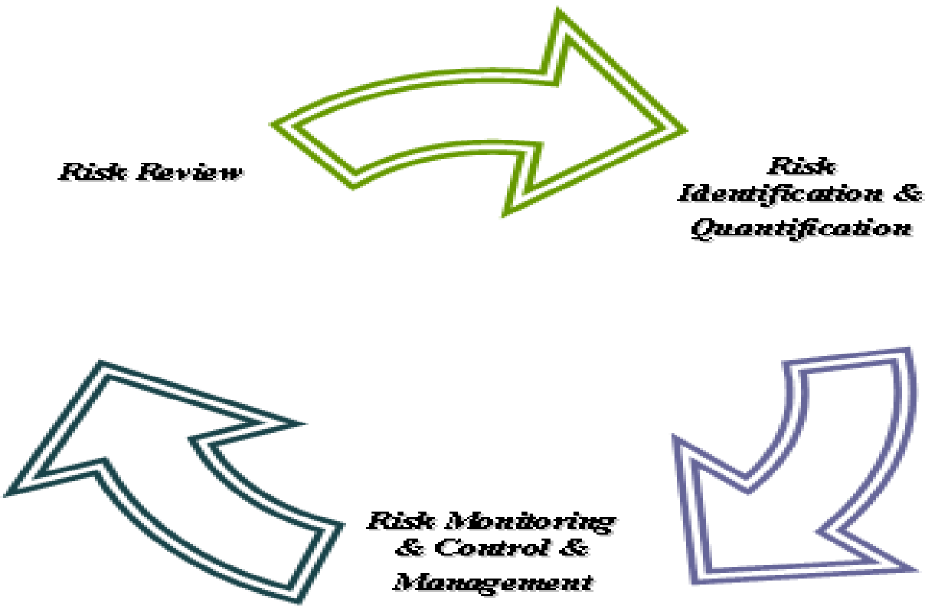


Figure 3.12 Solar photovoltaic power risk management procedure diagram (SPREE 2011)

In this diagram, five steps for the risk assessment process are illustrated including: the identification of hazards, anticipation of potential harm, evaluation of the risk, adoption of precautionary measures, implementation and the recording of findings and periodic reviews are identified.

The level of intensity of these risks varies so risk levels are therefore categorised as either major or minor. These categories are differentiated by the scale of loss that could be borne in both categories. The former type needs immediate action and implementation of safety measures, whereas the latter kind needs substantial precautionary measures to discourage their existence during operations. The main hazards associated with photovoltaics cells manufacturing, commissioning, operations and dismantling of the solar power plants are described below.

1. The solar photovoltaics cells manufacturing process is accompanied by the hazard of production of small amounts of carbon dioxide. Installed silicon-based cells pose risks to human health and the environment. The small amounts of semiconductor material present are released into the environment (Oregon 2011). However it is estimated that a 1 kW solar photovoltaic power system saves 460 kg of CO_2 a year, which is equivalent to 70 tonnes of greenhouse gas emission during the whole lifetime (Ecobuild 2011).

2. There are risks that electric shock may cause personal injury to installers, occupants or others (ESRUUS 2011). Electromagnetic fields are also produced by photovoltaic systems. This risk can harm both public and emergency responders. Though it comes in the negligible risk region, it needs proper attention by the design team, installation crew and system users. These risks, however, can be neutralised by the installation of a well-engineered insulated system and the displays of warnings to potential users.

3. There exist risks of initiation of a contact fire in the vicinity of a solar power generation plant It has a tolerable risk region and needs immediate attention by the plant safety personnel, so that the structure can be insulated with fire proofing materials, and fire drills at frequent intervals to train the plant personnel in accordance with the fire safety procedures (ESRUUS 2011). There is also the risk of fire at ground-mounted solar installations, which can be neutralised by the removal of fuels and flammable materials (glass and aluminium) contained in a solar panel (Oregon 2011).

4. There are chances of electromagnetic fields, which might be produced by photovoltaic systems However, these are not considered harmful to human health as they rapidly

diminish with distance and would be indistinguishable from normal background levels within several yards. This risk though not harmful can be lessened by the display of warnings and safety signs, so that the public and emergency responders may not be harmed (Oregon 2011).

5. There are risks of vandalism to a phototovoltaic module. However, these risks can be diminished by the use of appropriate design and system installation based on good engineering practice (ESRUUS 2011). It would safe to place PV modules the above the ground floor or at the first floor level.

6. It is believed that PV installation is hazardous because of a common misconception that solar power is a major mechanical, electrical and roofing challenge and a complicated addition to any building (Ecobuild 2011). This hazard is the result of a misconception and needs increased awareness, which can be accomplished by holding workshops for the demonstration of installation of solar photovoltaics.

7. The wrong orientation of the photovoltaic cells and the wrong inclination are important hazards for the power generation processes. These risks can be removed by the use of south facing or south east orientations and setting inclinations of 3, 10 degree and 50 degree tilts from the horizontal degree, which is optimal to produce about 70% as much energy as a south facing installation (Ecobuild 2011).

8. Regarding the hazard that solar cells produce less energy than it takes to make them, energy payback can be used to neutralise this hazard. For instance, the energy payback for standard and anticipated technologies of multicrystalline modules is four years for systems using recent technology and for thin-film modules paybacks it is three years (Ecobuild 2011).

9. There are hazards associated with the lack of routine maintenance of the modules and inverters in the phototvoltaic power plants. These hazards may reduce the efficiency and output of electrical power generation. However, this hazard can be controlled by the use of scheduled, preventive maintenance programmes, visual inspection of the panels and replacement of the inverter every 15 years (Ecobuild 2011).

10. There are also longevity and reliability hazards of PV cells. These hazards can be neutralised by the use of long life cells. In this regard, the use the PV cells which have a 20 to 25 year warranty of producing at least 80% of its optimal production would further ensure their longevity and reliability (Ecobuild 2011).

11. Photovoltaic power generation supply and demand hazards exist in a PV system when PV produces more electricity than is used. However, these hazards can be removed by selling the surplus electrical power to a local or national electricity supplier for subsequent feeding into the national grid (Ecobuild 2011)

Despite these risks the benefits of photovoltaics tend to far outweigh the risks, especially when compared to conventional fossil fuel technologies. The researchers at the Brookhaven National Laboratory believe that regardless of the specific technology, photovoltaics generate significantly fewer harmful air emissions (at least 89% per kilowatt-hour than conventional fossil fuel fired technologies) (Oregon 2011)**.**

3.15. Brackish water desalination processes

Various types of processes are used for the desalination of brackish water. Thermal and membrane processes can be used for the desalination of brackish water in these deserts. The thermal desalination processes such as Multistage Flash, Multifactor Distillation and Vapour Compression Distillation and the membrane processes of Reverse Osmosis and electro dialysis can also be used for the desalination of underground aquifer water (Singh et al 2008). The reverse osmosis process is considered the least energy-intensive method for desalination of brackish water for the remote places, and would optimise energy and costs. In electro dialysis process, desalinated water retains its original composition because water is not forced through a membrane (PCA 1989).

Considerable energy consumption savings in brackish water desalination processes are recorded. Brackish water desalination plants consumed around16 kWh/m^3 in 1984. The seawater RO desalination plant energy consumption reduced to8 kWh/m^3 in 1986. According to Madina (2004), improvements in efficiency came in 1996 with the introduction of Pelton turbines as recovery devices, by replacing the former Francis turbines with reverse running pumps, which enabled savings in energy consumption to 0.5

kWh/m^3 brackish water desalination. Furthermore according to Madina (2004), in 1999 a new improvement arrived in the reverse osmosis process with the new design of the Pelton wheel, which ha the capability to further reduce electrical power consumption by 0.3 kWh/m^3 for desalination.

Large scale brackish water desalination processes are used to cater for the needs of potable water for the communities living is far flung areas. For instance on the island of Jersey, a desalination plant produces 6000 m^3 of pure water per day, with the consumption of a total power of 2MW, with an energy cost of 8 kWh per m^3 of water produced, which included the electrical power consumption of the pumps for bringing the water up from the sea and through a series of filters (MacKay 2008). The plant burned 45,000 litres/day of heavy grade fuel oil prior to 1997; however in 1998 the plant was replaced with more energy efficient, less polluting and cheaper reverses osmosis desalination plant, which produced $6000m^3/d$ of freshwater for approximately 50% of the running costs of the old MSF plant (Merrett and Walton 2005).

3.16. Conclusion.

The literature on the existing energy sources such as fossil fuels, role of renewable energy sources, viability of solar energy, utilisation of desert resources, energy scenario in Pakistan, utilisation of desert resources to end lifestyle differences in Pakistan reveals the problems associated with fossil fuels can be resolved. The capability of solar energy is established in meeting the drinking, non-drinking, cultivation water and electrical power needs of the communities living in and around the deserts.

The review of solar technologies, solar thermal and photovoltaics, health, safety and environmental issues associated with solar product's lifecycle of photovoltaics pertaining to the solar cell's manufacturing, installation, dismantling and disposal leads to the conclusion that adoption of safety measures could be used to neutralise successfully their effects to men, material and the environment.

Chapter 04 Needs analysis

4.1. Introduction

The supplies of basic commodities such as water and food commodities are indispensable for the survival of the communities living in and around the desert areas. It is believed that the current levels of supplies of these commodities to those living in far flung areas are quite low. According to MacCalla (1994), the level of supplying these services to far flung places such as deserts is quite low. Furthermore according to MacCalla (1994), socio-economic disparities exist in these areas. However, the basic commodities supply conditions are less acute in the technologically advanced countries in comparison to the developing countries because the developed countries are capable to utilise of available renewable energy resources and alternative energy generation systems.

Disparities in the lifestyles exist in developing countries especially in rural and urban areas. The urban areas receive adequate amounts of power, water and food, and the system of supply is comparatively better than the rural and isolated areas (Ghaffar 1994). A scenario analysis is developed to build an understanding on the socioeconomic conditions of the people living in and around the desert areas. The analysis underline the need of initiatives, which would be required to explore the avenues of sustainable development based on indigenous resources, so that the process of available energy resources can be launched to improve the quality of life of the desert communities in environmentally friendly ways.

4.2. Scenario analysis on people living in and around the desert areas

A scenario analysis is developed to evaluate the current energy supply situation and their effects on socioeconomic and cultural sectors in the desert. In this scenario analysis, the people living in and around the desert communities in Pakistan are considered. In the analysis in two categories are assumed. In the first category, it is presumed are those communities that are at a subsistence level and in the other category are communities that are above subsistence level. The people living in the communities at subsistence level are those communities, which lack adequate amounts of electrical power, potable water and food. While people living in the communities above subsistence levels are those, which obtain adequate amounts of basic commodities such as electrical power, potable water and food. It is presumed that the electrical power, potable water requirements of these communities increase in the summer due to increased environmental temperature. The communities below subsistence are denoted by “S and that above subsistence are denoted by “A”, as is illustrated in Figure 4.1.

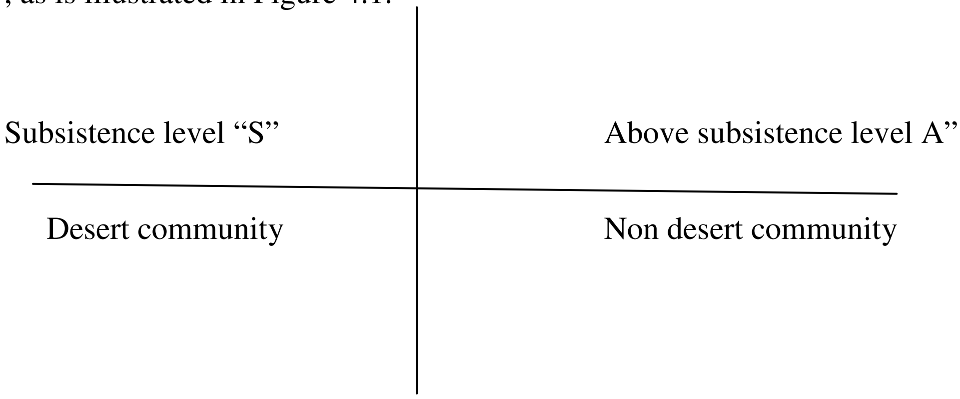


Figure 4.1: Scenario analysis I showing the desert and urban communities.

Because of the differences in lifestyle levels of communities at and above subsistence levels, a process of movement of communities to other areas in search of these resources takes place (Soharwardi 2011; Ghaffar 1994). It is believed that the communities living in the cities and towns receive considerable amounts of energy such as electrical power and natural gas. In the first scenario it is considered that in the event of lack of availability of adequate amounts of potable water and food, electrical power and natural gas these communities move towards the towns, as is shown in Figure 4.2

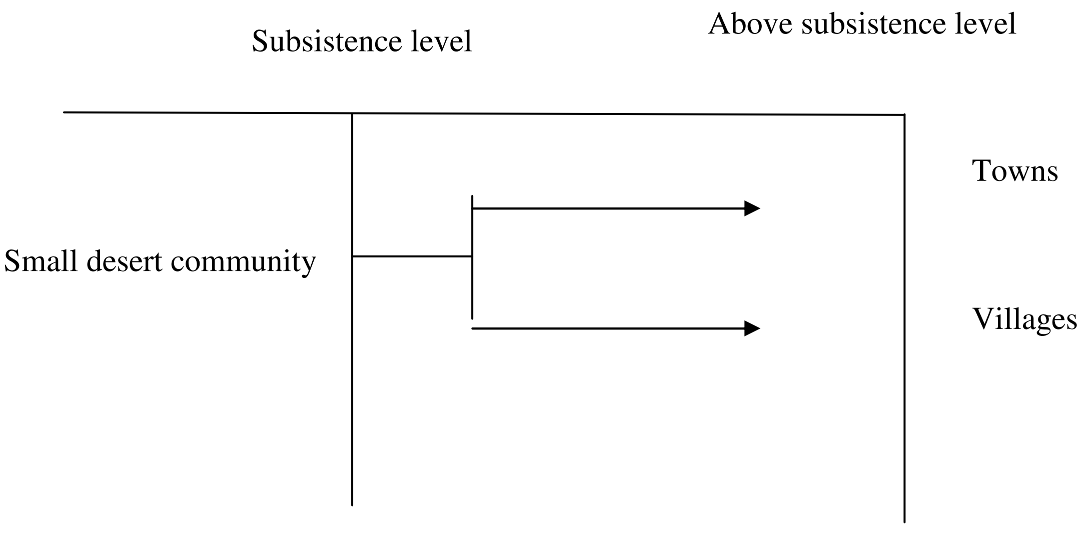


Figure 4.2: Scenario analysis II showing the movement of desert communities.

The effects of such movements of desert communities are negative on the economy, society and culture because of increase in demographic, social and economic disparities. However, if subsistence products such as water, electrical power and food are provided at specified regions, it could stop the movement of these communities.

In the second scenario it is presumed that in the event of lack of availability of energy generation and supply system, the people living in these communities do not receive adequate amounts of potable water food, electrical power and natural gas, and move towards the main cities, as is illustrated in Figure 4.3.

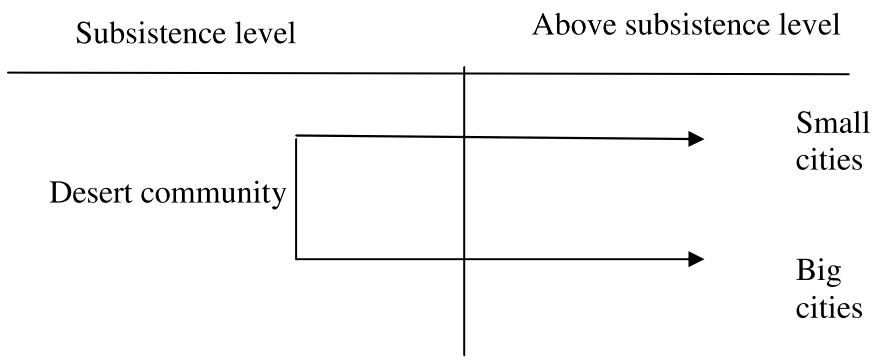


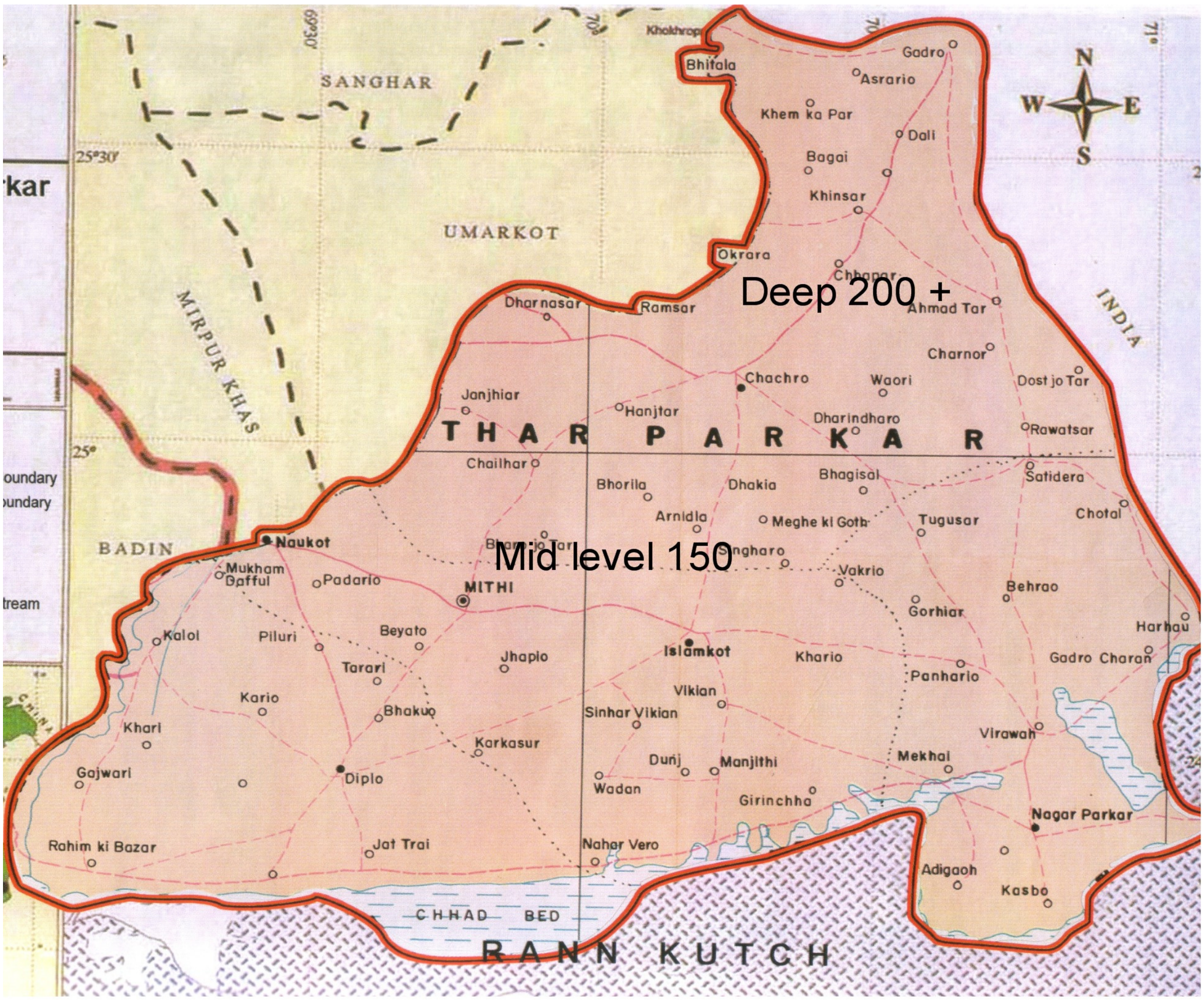
Figure 4.3: Scenario analysis III showing the movement of desert communities

Since the cities are overpopulated, the quality of life of recently moved communities is affected adversely, and theses people suffer social and economic disparities. Psychological problems emerge due to socioeconomic disparities of the existing and migrated communities. These problems are complicated with the passage of time.

Both the scenarios reveal the need for an environmentally sustainable energy generation development programme based on the use of indigenous energy resources, so that the quality of life of these communities could be improved. Such developments could bring an improvement in the quality of life of the majority of the population in Pakistan.

4.3. Needs analysis

A process of needs analysis for people living in and around the desert at Thar, Pakistan is carried out. The objective of this exercise is to specify the process of needs analysis per person per day. The basic needs of electrical power, water and food of the people living in and around the deserts are included in this analysis. The map showing the density of desert communities in the Tharparkar district, Pakistan is given in Figure 4.4.



Urban population (towns) **Rural population villages)**

Figure 4.4. Map of Thar Desert (Drynet 2011)

The total population of the Tharparker district is bifurcated in urban and rural communities. According to district government Tharparker (2012), the total non urban population and area are 874519 and 18852 kilometres, and the total urban population and area are 39824 and 854 kilometres, and the density of population in villages and towns is 47 people per kilometre. The locations of desert communities including Islamkot and are shown in Figure 4.5.

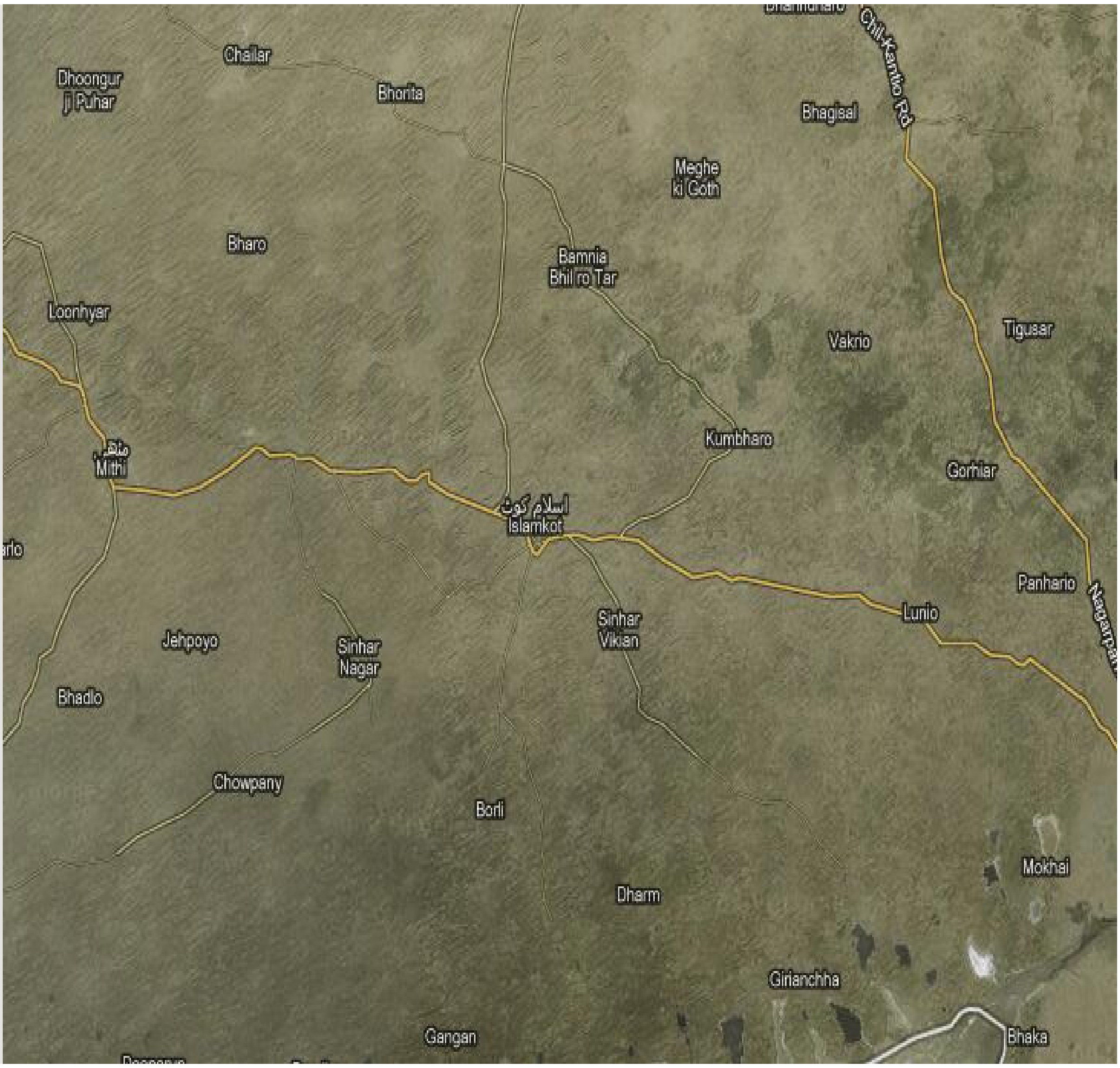


Figure 4.5. Map of Thar Desert showing the location of Islamkot, Thar Desert (Googlemap 2011)

The density of the population is quite thin and the amount of solar radiation is quite high at the Tharparkar district, Pakistan. However, these deserts location are popular for high radiation solar energy opportunities.

4.4. Total energy needs per person per day in a desert community

In order to build an understanding on the nature and volume of the basic needs of the people living in and around the deserts, these needs are identified and estimated per person per day. These needs are of: potable water, electrical power and food. The break down of food, water and power needs is furnished with the aim of facilitating the estimation process accurately and precisely.

On the basis of the total amounts of water, electrical power and food, total volume of energy required for the production of required per person per day are estimated. The consumption of commodities per person per day is calculated on the basis of the water, food and electrical power consumption patterns in Pakistan.

Total electric power needs include the additional amount of energy that would be lost in the transmission and distribution network. Transmission and distribution losses are assumed to be 20%, on the basis of distribution and transmission losses prevalent in Pakistan in the year 2009 (EPTDLP, 2009).

The total amounts of energy (kWh) per person per day in a desert community are calculated in Tables 4.1. The break down of total amounts of drinking, non-drinking and cultivation water and electrical power are given in subsequent tables 4.2, 4.3 and 4.4.The total energy value obtained per person per day can be scale up for any number of persons in desert communities per day.

Table 4.1. Break down of electrical power consumption on aquifer water pumping and brackish water desalination per person per day (kWh) and the calculation of total electrical power per person per day (kWh) required to cater the needs of pumping, brackish water desalination and domestic power in a desert community at Islamkot, Thar, Pakistan (Madina 2004; Ehrlich 2011; RSEA 2011).

PUMPING Electrical power consumption on pumping of underground aquifer water for drinking, non drinking and cultivation per person per day (kWh)	DESALINATION FOR POPULATION Electrical power consumption on desalination of water for drinking and non-drinking per person per day (kWh)	DESALINATION WHEAT Electrical power consumption on desalination of cultivation water for wheat per person per day (kWh)	DESALINATION RICE Electrical power consumption on desalination of cultivation water for rice per person per day (kWh)
0.387	0.095	0.020	0.245
DESLAINATION PULSES Electrical power consumption on desalination of cultivation water for pulses per person per day (kWh)	DOMESTIC Electrical power consumption for domestic use per person per day (kWh)	TOTAL Total electrical power consumption on desalination of water for drinking, non-drinking, crops cultivation and domestic power per person per day (kWh)	TOTAL WITH T&D LOSSES Total electrical power consumption on desalination of brackish water and domestic power use per person per day, allowing for 20% T&D losses (kWh)
0.027	1.35	2.12	2.54

The breakdown reveals total amounts of energy required per person per day to meet their water, food and domestic electrical power needs. It is presumed that if this amount of energy is produced locally it would resolve the problems of import of energy from other areas.

4.5. Water needs of people living in desert communities

As mentioned, the supply of potable water is also a main problem of the people living in and around the desert areas of Pakistan. Rain water, which is only sources of water available, could not mitigate their water problems. The rains that occur during the monsoon period either evaporate or infiltrate (Zaigham 2001). Monsoon rain is a geographical phenomenon, which takes place because of cyclic air movements changing with the time of year and occurs in certain regions of the Earth, Pakistan and India being few of them. In the absence of water treatment and desalination plants, unhygienic drinking water is consumed by these communities (Palijo 2011).

The water shortage problem is complicated due to continuous increases in water demand on account of the increase in the population. In the absence of alternative arrangements for water supply, the problem remains intact. Their water needs are neither met adequately from rain stored water nor from existing dug wells situated over long distances. Therefore, the need for exploration of potable water production systems is felt badly in these areas (Kahlown 2004). The underground aquifer water is not usable for meeting the water needs of these communities due to the high levels of salinity. Desalination of underground aquifer water is not currently provided on large scale because of the lack of availability of an electrical power source, required for the pumping and desalination of the brackish water (Zaigham 2001).

4.5.1. Total water needs per person per day in a desert community

The estimation for drinking, non-drinking and cultivation water needs for the people living in and around the desert areas is carried out to develop an idea about total water demand per person per day. Drinking water consumption quantities are based on standard clinical drinking water amounts per person per day (Mayoclinic 2011). The water usage calculator is used for the calculation of the non-drinking water consumption per person per day (WCC 2011). The water calculator includes indoor potable drinking water and water usage in the bathroom, toilet and kitchen for flushing, brushing, shaving, bathing, cooking and cleaning dishes.

The power consumption in the desalination and pumping process is based on the assumption of 0.3 kWh and 1kWh per m^3 of desalinated water. Electric power consumption on pumping of one m^3 of underground water is 1kWh (Ehrlich 2011). The total electrical power consumption of the desalination process is obtained by multiplying the total amount of water with the total amounts of brackish water that would be desalinated in m^3.

The ratio of the desalinated water output-volume to the seawater input-volume used to produce it is called the water recovery ratio. The reverse osmosis process desalination process can obtain a 40% recovery rate, depending on the depth of the well and the salinity level of the raw water (Pimentel et al 1994). The potable water recovery ratio is taken as 40:60; meaning that for every 1 m^3 of brackish water used in the desalination process, only 0.4 m^3 of potable water can be obtained. Therefore, brackish water amounts of more than the total calculated water are required in the desalination process. These allowances are provided in the table on total electrical power consumption.

The volume of water pumped and desalinated can be increased in gradual phases. Surplus potable water can be sold to the populations living in urban and rural areas. Potable water is a precious commodity and can also be used a source of revenue. The revenue generated from the sale of potable water can be used to purchase the food commodities required for the desert communities. The revenues can be used for building sustainable development processes in and around the desert areas.

The cultivation water calculations are based on the amounts of water that are consumed per 10^3 kg of the cultivation of wheat, rice and pulses cultivation in Pakistan (Choudhri et al 2001; Khan et al 2001; Mekonnen and Hoekestra 2011). The break down of the total drinking and non-drinking water per person per day water in a desert community is given in Table 4.2.The total number can be scaled up for any number of persons.

Table 4.2 Break down of specific amounts of water required to cater for the needs of drinking and non-drinking per person per day (m^3) in a desert community at Thar, Pakistan (WCC 2011).

Drinking water per person per day (m^3)	Flushing water per person per day (m^3)	Brushing water per person per day (m^3)	Bath water per person per day (m^3)	Washing water per person per day (m^3)
0.002	0.006	0.006	0.040	0.010
Shaving water per person per day (m^3)	Dish clean water per person per day (m^3)	Cooking water per person per day (m^3)	Total drinking and non-drinking water consumption per person per day (m^3)	
0.006	0.014	0.011	0.095	

4.6. Electric power needs of people living in desert communities

Water heaters, air coolers, lights, refrigerators, air-conditioners, vacuum cleaners, computers and televisions all require an electrical power supply. However, due to the lack of an electric power supply system in the deserts, the lighting, heating, and cooling needs of the people could not have been met adequately (Ghaffar 1994). It is believed that about 68-70% of the country's population, who lives in rural areas including, have no access to commercial energy and use unsustainable means to meet their needs of heating, cooling and lighting (Harijan et al 2007).

Alternatively, wood and dung are used for cooking and lighting, which have negative effects on the people's health and the environment (Ghaffar 1994). The entertainment needs of these communities also remain unsatisfied, as televisions, the internet, computers and multimedia equipment are all electrically powered.

Since the electrical power needs of the people living in and around the desert areas are not being met by the conventional means of power supply such as thermal and hydro power plants, which are located near to main cities, it is essential to look for alternative means that are available and could be capable of providing for the electrical power needs in a sustainable manner.

It is presumed that if the energy fuel is indigenous, it could be possible that that the problems of the transmission line costs can be reduced by the development of self-contained electrical power systems, since the electric power needs are bound to increase with the passage of time.

4.6.1. Total domestic electrical power needs per person per day in a desert community

The electrical power needs for heating, lighting, washing cooling, vacuuming and cleaning per person per day are calculated in kWh. The total domestic electrical power consumption per person per day is calculated on the basis of specific consumption in lights, fans heaters, television and ironing.

The breakdown of domestic electric power consumption per person per day in desert community is shown in Table 4.3. The total electrical power consumption used on lighting, cooling and entertainment per day is scalable, and can be scaled up for any number of persons.

Table 4.3. Break down of domestic electrical power consumption per dwelling and per person (kWh) and the calculation of total domestic electrical power consumption (kWh) in a desert community at Thar, Pakistan (CPI 2011).

Electrical power consumption on water well pump per dwelling per day (kWh)	Electrical power consumption on TV per dwelling per day (kWh)	Electrical power consumption on lighting per dwelling per day (kWh)
3	0.6	0.33
Electrical power consumption on ceiling fan per dwelling per day (kWh)	Total electrical power consumption per dwelling per day (kWh)	Electrical power consumption per person per day (kWh)
2.83	6.76	1.352

4.7. Agricultural needs of people living in desert communities

As mentioned, due to the lack of availability of a water source, the capabilities of the desert land to produce crops such as wheat, rice and pulses are seriously affected. The deserts land are characterised by the problems of soil infertility, water logging, salinity and dryness (Kahlown 2004). However it is presumed that if the agricultural water needs of the desert communities are met, the problems of lack of availability of agricultural commodities can be resolved and food self-sufficiency can be attained.

It is presumed that Agricultural output can be increased by the conversion of barren desert land into fertile land. The problems of lack of availability of cultivation water can be resolved by the utilisation of indigenous desert resources such as underground aquifer water and solar power generation. It is believed that if the solar electrical power generation system is developed, it is possible that the underground aquifer water can be pumped to the surface and can be used for drinking and cultivation in these desert sites (Zaigham 2001).

4.7.1. Total agricultural needs per person per day in a desert community

In order to realise the practical implications of this approach, the quantities of consumption of agricultural commodities per person per day in a desert community are estimated. The total amount of consumption is estimated on the basis of the amounts of eating of wheat, rice and pulses per person per day (Chaudhry et al 2001; Khan et al 2001, Mekonnen and Hoekestra 2011, Nauman et al 2011). The break down of the agricultural commodity consumption per person per day in a typical desert community is provided in Tables 4.4. The total can be scaled up for any number of persons.

.

Table 4.4. Break down of wheat, rice and pulses consumption per person per day (kg) and the calculation of total amounts of wheat, rice, pulses per day (kg) and water required for the cultivation of the wheat, rice and pulses per person per day (m^3) in a desert community at Thar, Pakistan (Chaudhry et al 2001; Khan et al 2001, Mekonnen and Hoekestra 2011, Nauman et al 2011)

Crop type	Crop consumption per head per day (kg)	Wheat seed/10^3kg crop cultivation per day (kg)	Total crop quantity necessary per person per day (kg)	Crop cultivation water/10^3 kg crop cultivation (m^3)	Crop cultivation water allowing for water recovery ratio (60:40) (m^3)	Total crop cultivation water per person per day (m^3)
Wheat	0.32	29	0.412	0.30×10^3	0.49×10^3	0.020
Rice	0.042	27	0.0534	2.66×10^3	4.59×10^3	0.245
Pulses	0.0037	139	0.0042	38.5×10^3	6.48×10^3	0.027

4.8. Conclusion

Needs analysis process has facilitated in the identitification and estimation of total quantities of potable water, electrical power, wheat, rice and pulses that would be required per person per day. The total amount of energy per person per day in a desert community is calculated as 2.54 kWh.

The total drinking, non-drinking and cultivation water per person per day is 0.095 m^3 respectively. The total electric power consumption per person per day is 1.35 kWh. The total volume of the commodities of wheat, rice and pulses consumption and power consumption and subsequent amounts of energy per day for desert community can be calculated accordingly.

Chapter 05 Desert energy utilisation model scenarios

5.1. Introduction

In order to generate the required amounts of energy for the processes of potable drinking, non-drinking and cultivation water and electrical power for the people living in and around the desert areas, it is essential to workout a self-contained desert energy utilisation that could cater for the cater for needs in a self-contained and environmentally sustainable manner.

There are two kinds of models generally used for the solution of problems; those which present the problems and their solutions in a system and others, which are used to devise solutions to the problems on the basis of the experience gained while participating in the same activity (PTG 2003). The models in the current research pertain to the latter category. In our case, desert energy model is used to develop the scenarios that can predict positive changes to the energy generation process. The model scenarios are accompanied with strategies for the production of useful commodities.

The modelling of desert energy processes is based on the principle of effective utilisation of desert resources such as high radiation solar energy and underground brackish water. In scenarios-I, II and III, the processes of solar phototovoltaic power generation, solar desalination, brine electrolysis, ammonia synthesis, urea synthesis and outputs besides energy and mass balance are developed. The spreadsheets for energy calculation under scenario I-III and IV are developed, which are illustrated in tables 5.1 and 5.2. However, in scenario-IV, only the processes of solar power generation and desalination processes are retained.

5.1.1. Desert energy utilisation model scenarios

In the scenarios I, II, III and IV are developed on the basis of the issues associated with each scenario of energy utilisation. Detailed description of each scenario is given in the following section.

The basic inputs under these scenarios are underground brackish aquifer water, air and solar energy. The prime objective of these scenarios is to develop a model that can be used to utilise the desert resources for facilitating a self-contained and decentralised energy generation and supply mechanism.

Transmission and distribution losses in the transport are included in the total amounts of energy that would be required under each scenario. 20% T&D losses are added to the total energy requirements of the model for both a small and large desert community.

It is believed that there is considerable demand for the commodities of potable water, food and electrical power in the deserts and the adjacent areas. It is also believed that a local market for the utilities of electrical power and potable water can be developed in and around the desert areas, which would facilitate the process of supply of these commodities to the areas not covered by the national grid and water supply system.

5.2. Desert energy utilisation model scenario I

Model scenario-I uses the inputs of solar energy, seawater, air, and CO_2 and produces the outputs of electric power, potable water, chlorine, sodium hydroxide and urea. In this scenario, the inputs of seawater, air, solar energy and coal are processed through the processes of solar photovoltaic power generation, brine electrolysis, air separation, oxy-fuel combustion, ammonia synthesis and urea synthesis to get the intermediate products of brine, chlorine, sodium hydroxide, ammonia and carbon dioxide plus the output products of electric power, pure water and urea. The layout of desert energy utilisation scenario is illustrated in Figure 5.1.

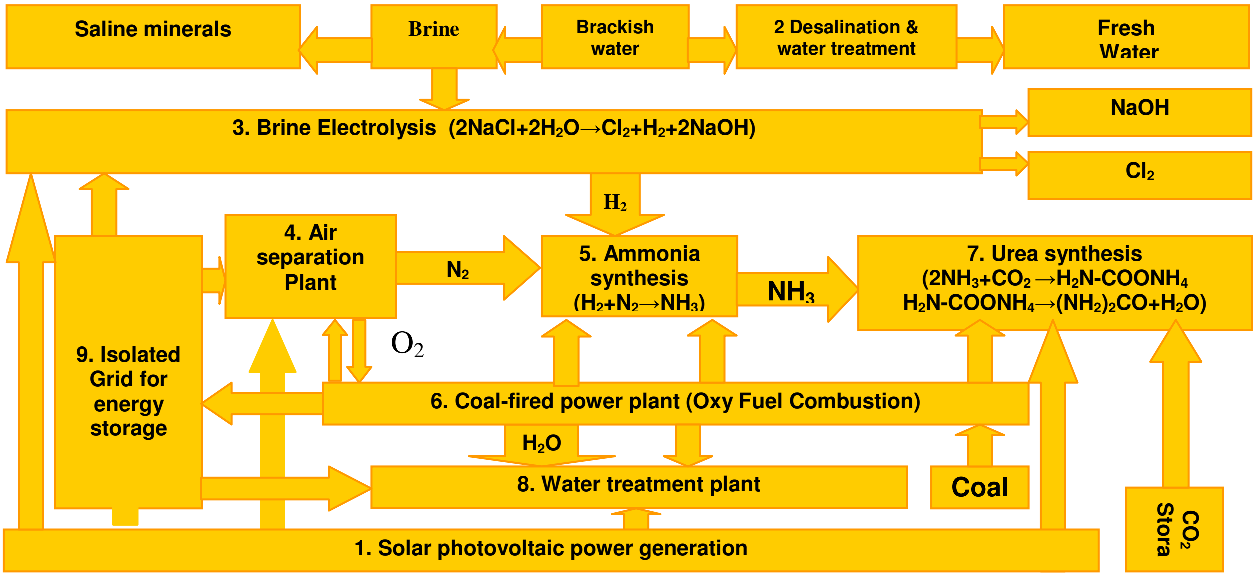


Figure 5.1. Layout of desert energy utilisation model scenario I

It is presumed that potable water is produced through solar desalination in the first stage. In the second stage, H_2, NaOH and Cl are produced through a brine electrolysis process. The ammonia is produced by synthesizing H_2 and N_2 in the third stage**.** The latter is produced by an air separation process**.** The O_2 generated in the air separation plant is also utilized for the oxy-fuel combustion process, which generates electricity and CO_2. The CO_2 can be sequestrated by combining with NH_3 to obtain urea. An electricity grid is provided in the model to ensure an uninterrupted power supply from the solar energy accumulated during the day.

The maximum amount of brine in seawater is assumed as 3.2% and the ratio of seawater to desalinated potable water desalination is presumed as 60:40. The amounts of electrical power consumption required in brine electrolysis, air separation, ammonia synthesis and urea synthesis processes are assumed on the basis of their consumption values available in the published literature (Gujrat 2005; Marvoric and Glade 1999; Scientist 1972). The description of the numbered layout of these processes is given below:

1. The solar photovoltaic electricity generation process is devised as the means of electrical power generation and supply of electric power for the processes of pumping of underground aquifer water, desalination of aquifer brackish water, brine electrolysis, air separation, ammonia synthesis and urea synthesis processes.

2. With the abundant electrical power provided in the desert, brackish water desalination is a natural way forward. A reverse osmosis desalination of underground aquifer water is used for the production of potable water. This is assuming there is 3.2% NaCl in the seawater and seawater to potable water recovery ratio of 40%. Potable water is the most important factor for the creation of a hospitable environment, and can be made available by these processes in a desert. Underground aquifer water can be used as an input for the desalination process (Zaigham 2001).

3. The concentrate from the desalination process is conveniently utilized as an input for the electrolysis process to generate H_2, Cl_2 and NaOH as illustrated in Eq. (5.1). The brine is salt saturated water. The salt concentration by weight in brine at 15.5°C is 26.4% and at 0°C is 26.3% (Brinechiller 2011).

$$2NaCl + 2H_2O \rightarrow Cl_2 + 2H_2 + 2NaOH \quad (5.1)$$

$$2NaCl(3.24x10^3kg)+2H_2O \rightarrow Cl_2 (1.96\ x10^3kg)+H_2(0.05x10^3kg)+2NaOH(2.2x10^3kg) \quad (5.2)$$

The molar masses of the brine, water, chlorine, hydrogen and sodium hydroxide, are used to determine their quantities, as shown in Eq. (5.2). It is calculated that for every 1 m^3 of brackish water; 0.05 $x10^3$ kg of hydrogen, 1.96 $x10^3$ kg of chlorine and 2.1 $x10^3$ kg of sodium hydroxide can be produced. Of these three products, hydrogen can be processed with nitrogen to obtain ammonia, as is shown in Eq. (5.3).

4. In this scenario, it is opined that the oxygen and nitrogen can be produced by the use of an air separation process in this scenario. Air can be utilized in the air separation process to produce nitrogen and oxygen. Both substances are utilized as inputs at the second stage of the desert economy model. Nitrogen is synthesized with hydrogen to get ammonia in the ammonia synthesis process, and oxygen can be utilized in the oxy-fuel combustion process.

5. Hydrogen and nitrogen are synthesized to obtain ammonia (Modak 2011). The Haeber process equation for ammonia synthesis is shown in Eq. (5.3) and (5.4). The purpose of this process is to produce an ingredient for urea production.

$$N_2 + 3H_2 \rightarrow 2NH_3 \quad (5.3)$$

$$(0.33 \text{ x}10^3 \text{ kg})N_2 + (0.15 \text{ x}10^3 \text{ kg})\ H_2 \rightarrow (\ 0.1 \text{ x}10^3 \text{ kg})\ NH_3 \quad (5.4)$$

The molar mass calculations reveal that for each 0.05x10^3 kg of hydrogen, as obtained at brine electrolysis, 0.05x10^3 kg of nitrogen is needed, which could produce 0.1 x10^3 kg of ammonia.

6. In the scenario, it is believed that CO_2 can be captured either by the removal of nitrogen from flue gases or by the removal of nitrogen from the air before combustion, to obtain a gas stream ready for geo-sequestration. The techno-economic studies reveal that oxy-fuel combustion is a cost-effective method of CO_2 capture (Buhre eta al 2005). A coal-fired oxy-fuel power generation process is built into the energy model to produce electrical power and CO_2.

7. In this scenario, it is opined that CO_2 and ammonia can be utilized to produce urea by use of the urea synthesis process. In this process, ammonia and carbon dioxide are fed into the reactors at high pressure (240 barg), and the urea solution is then concentrated to give 99.6% molten urea, and granulated for use as fertiliser and chemical feedstock (Marvoric and Glade 1999). The urea synthesis process is illustrated in Eq. (5.5) and (5.6).

$$NH_3 + CO_2 \rightarrow (NH_2)_2CO + H2O \quad (5.5)$$

$$(0.1 \text{ x}10^3 \text{ kg})NH_3 + 0.1\text{x}10^3 \text{ kg})CO_2 \rightarrow (0.1 \text{ x}10^3 \text{ kg})(NH_2)_2CO + (0.1 \text{ x}10^3 \text{ kg})\ H_2O \quad (5.6)$$

The molar masses of ammonia and carbon dioxide are used in these equations and these values are based on use of one tonne of seawater. Therefore, for every 0.1 x10^3 kg of ammonia, 0.1 x10^3 kg of carbon dioxide is required, which produces 0.1 x10^3 kg of urea and 0.1 m^3 of desalinated water.

8. In this scenario, it is believed that the major impurities from the urea production reaction, including water and unconsumed reactants such as; ammonia, carbon dioxide and ammonium carbamate could be removed in three stages. Firstly, the pressure is reduced from 240 to 17 barg and the solution is heated, which causes the ammonium carbamate to decompose into ammonia and carbon dioxide. The pressure is then reduced to 2.0 barg and finally to -0.35 barg, with more ammonia and carbon dioxide being lost at each stage, and

a solution of urea is dissolved in water, free of all impurities (Marvoric and Glade 1999). The drain water obtained from the urea synthesis process can be treated further to convert it to a pure form, which could be utilized for drinking and for cultivation.

9. In this scenario, an isolated-grid" application is used so that the PV system feeds electrical energy directly into the grid. Batteries are not necessary when the power generation system is grid-connected. The grid-connected PV power generation would enable the storage of electrical power during the day that could be supplied during the off-solar hours.

The break down and total electrical power consumption in desalination, underground brackish water pumping and domestic power consumption including transmission and distribution losses per person per day, in year 1 is calculated in Table 5.1.

5.2.1. Issues with scenario I

The handling of chlorine and sodium hydroxide are environmental issues for the desert communities and local fauna. Therefore means to either eliminate the chlorine or to further process it to get other substances is worked out.

Table 5.1. Breakdown of electrical power consumption in brine electrolysis, air separation ammonia synthesis, urea synthesis and brackish water desalination processes, based on drinking, non-drinking and cultivation water per person per day (kWh), and the calculation of total electrical power required per person per day (kWh) under energy model scenarios I, II and III (Ehrlic 2011; Gujrat 2005; Marvoric and Glade 1999; Chedd 1972).

Electrical power consumption in brine electrolysis per day (0.387 m^3) @2100 kWh/10^3kg (kWh)	Electrical power consumption on air separation per day ($0.05x10^3$ kg N_2) @1100 kWh/10^3kg (kWh)	Electrical power consumption in ammonia synthesis per day (0.1x10 kg) @ 7000 kWh/10^3kg (kWh)	Electrical power consumption on urea production per day ($0.1x10^3$ kg) @75kWh (kWh/day)	Total electrical power consumption on brine electrolysis, air separation, ammonia and urea synthesis per day (kWh)	Total electrical power consumption on brine electrolysis, air separation, ammonia and urea synthesis allowing for 20% T&D losses per day (kWh) A
1625	55	700	75	2076.2	4531.2

Electrical power consumption on desalination of drinking and non-drinking water per person per day (kWh)	Electrical power consumption on desalination of cultivation water for wheat per person per day (kWh)	Electrical power consumption on desalination of cultivation water for pulses per person per day (kWh)	Electrical power consumption on desalination of cultivation water for rice per person per day (kWh)	Electrical power consumption on pumping of drinking, no drinking and cultivation water per person per day (kWh)	Domestic electrical power consumption per person per day (kWh)	Total electrical power consumption on desalination and domestic use per person per day (kWh) B
0.095	0.006	0.0081	0.0735	0.387	1.35	2.12

Total electrical power consumption on pumping, brackish water desalination and domestic electrical power consumption per person per day (kWh) A+B	Total electrical power consumption on brine electrolysis, air separation, ammonia synthesis, urea synthesis, brackish water desalination and domestic power per person per day allowing for 20% T&D losses (kWh)
4533.32	5439.98

5.3. Desert energy utilisation model scenario II

In scenario II, the mode of solar power generation is retained as solar photovoltaic. However, output product chlorine is processed further to get sodium bicarbonate and hydrochloric acid, as illustrated in Table 5.1. The other processes of the energy model as described in the model are, however, the same. The layout of desert energy utilisation scenario-II processes are illustrated in Figure 5.3.The total energy consumption for pumping, desalination and electrical power generation under scenario II, for the year 1 are retained, as calculated in Table 5.1.

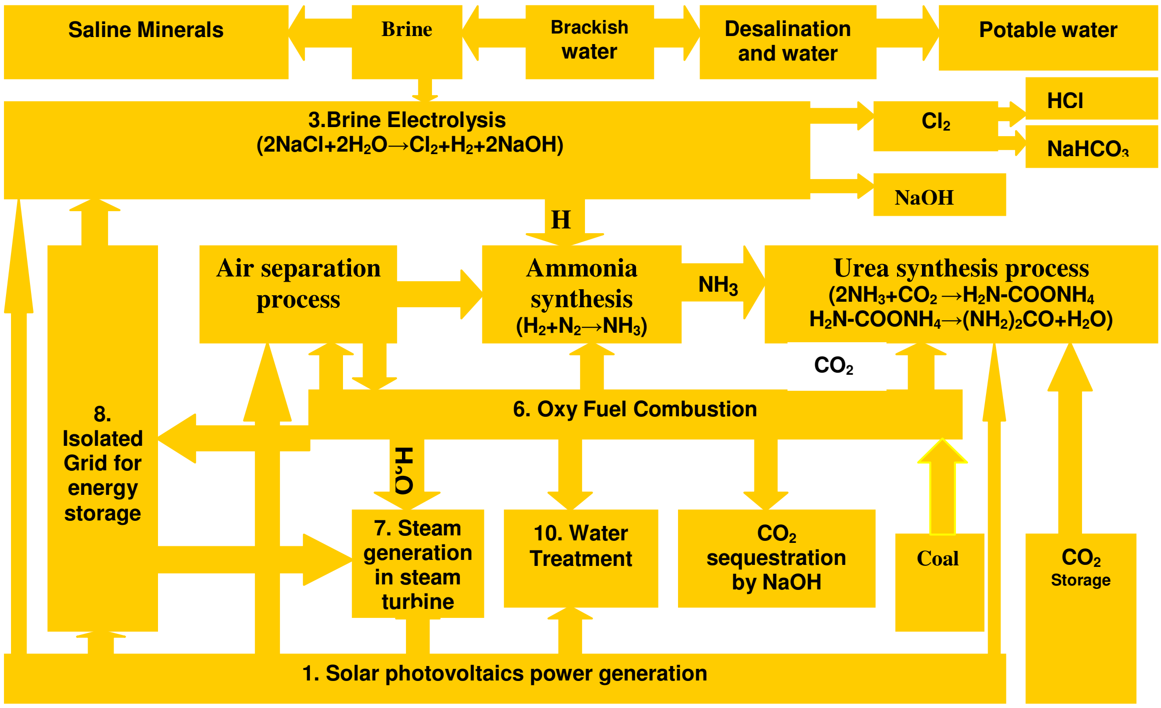


Figure 5.2. Layout of desert energy utilisation model scenario II

5.3.1. Issues with scenario II

Solar energy is a capital intensive technology. It is assumed that the high capital costs of the installation of solar power plants could discourage or delay the process of utilisation of desert utilisation process, as stipulated in scenario II. Therefore alternative revenue means are worked out for financing the costs of large scale solar power generation and desalination plants.

5.4. Desert energy utilisation model scenario III

This scenario is developed keeping in view the deserts coal reserves. In this scenario energy generation costs optimisation process is analysed. Under this scenario it is proposed that the revenues generated from coal sales could be used to finance the solar equipment's total capital costs. In this scenario the the processes enumerated in scenario II processes are retained. The layout of the intermediate desert development model is given in Figure 5.3. The total energy consumption for pumping, desalination and electrical power generation under scenario III, for the year 1 are same, as calculated in Table 5.1.

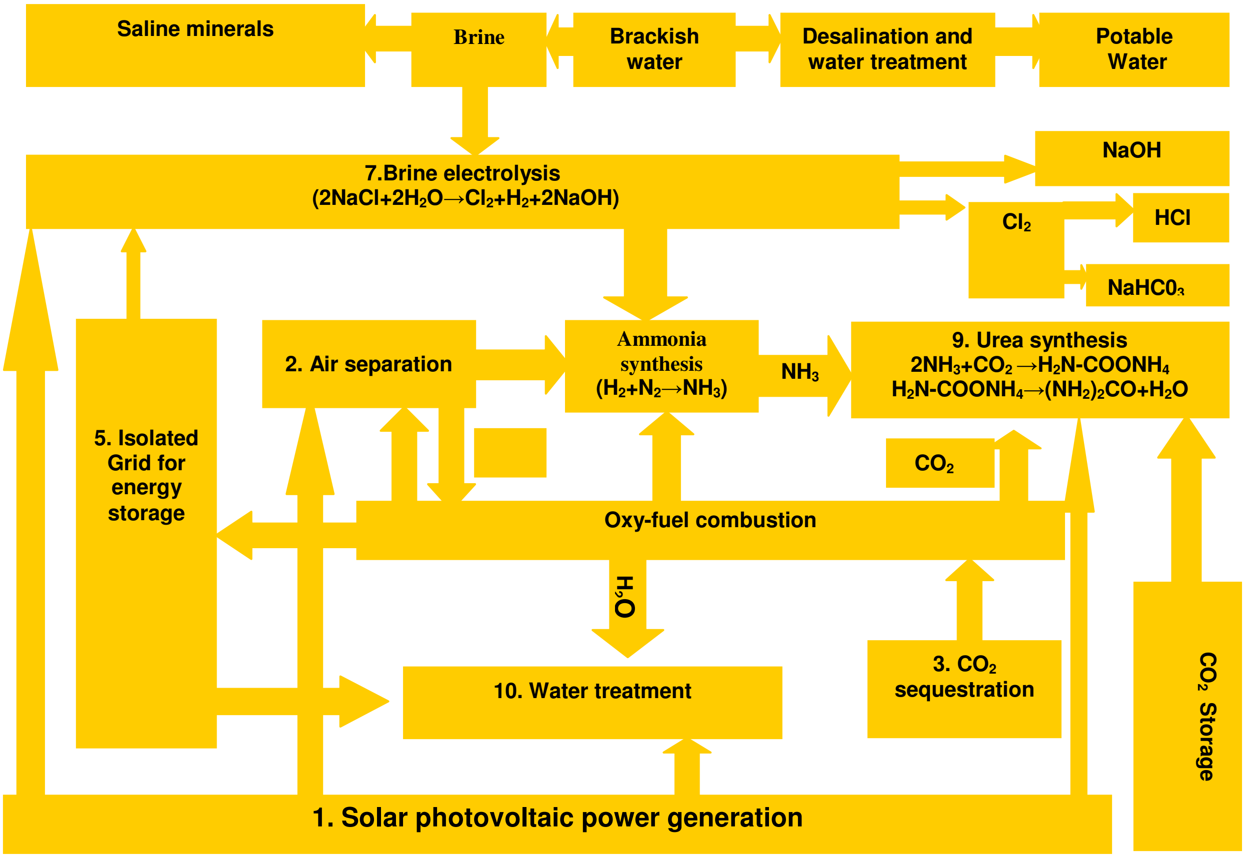


Figure 5.3. Layout of desert energy utilisation model scenario III

5.4.1. Issues with scenario III

Seawater contains higher concentrations of total dissolved salts than underground water aquifers. In seawater the total dissolved salts are 35000 ppm in comparison to brackish water, which has total dissolved salts in the range of 5500 to 15000 ppm (Appslab 2011. Seawater has a high proportion of sodium chloride and this is around 28000 ppm. Also, the cost of transportation of seawater from coastal areas to desert sites is an economic issue. Furthermore, the total volume of energy consumption of brine electrolysis, air separation, ammonia synthesis and urea synthesis is considerable.

5.5. Desert energy utilisation model scenario IV

The processes of brine electrolysis, air separation, ammonia synthesis and urea synthesis are eliminated in this scenario. Moreover, the input water source for the desalination process is changed from seawater to underground aquifer brackish water. In desert energy model scenarios I, II and III, seawater is proposed because of the objective of the production of electrical water, potable water, urea, caustic soda and hydrochloric acid. Underground aquifers can also be used for scenarios I, II and III, provided the products of caustic soda, urea, hydrochloric acid and sodium bicarbonate are not produced.

Underground replenishable aquifers are available at Thar Desert, which can be pumped to the surface and used as input to the desalination process. According to Zaigham (2001), the results of the study, carried out on exploration of underground aquifers at Thar, reveals that perch water aquifers are present at the bottom of the dunes and-zone, with fluctuating yield controlled by the annual rainfall cycles. There are places such as vertical electric-soundings, which indicate bright prospects for potable water. Furthermore according to Zaigham (2001), strategic development of groundwater from the deep sedimentary and basement aquifers can dedesertify the Thar, which would accelerate a process of socioeconomic stability in the region

Under this scenario, total amounts of energy can be reduced by the elimination of brine electrolysis, air separation, urea synthesis and ammonia synthesis processes.The desert energy model scenario IV is illustrated in Figure 5.4.

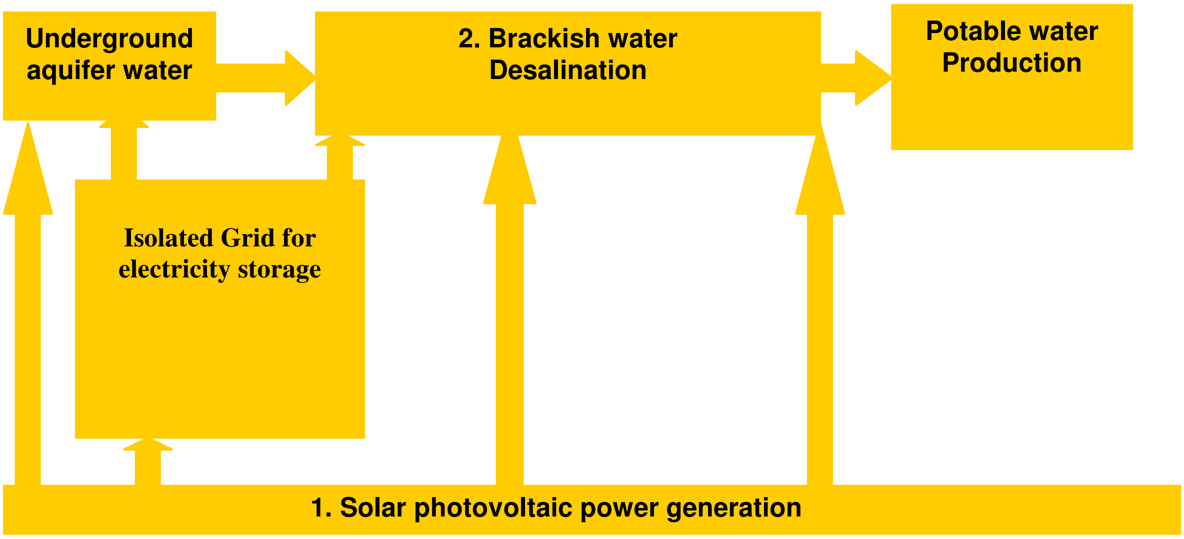


Figure 5.4. Layout of desert energy utilisation model scenario IV

The scenario IV is developed with the objective of bringing down the total energy values requirements and the total solar equipments capital costs. Since the total volume of energy required is small in this scenario, the size of investment would also be reduced.

The methodologies of the energy calculations are discussed in the needs analysis. The purpose of providing it here is solely to maintain the consistency in the presentation of energy models and energy requirements, and to differentiate it in terms of reduction in the total energy requirement.

The outputs of the desert energy model under scenario IV are potable water, electrical power and salts. It is presumed that the volume of these outputs can be enhanced to cater for an increase in the total energy requirements because of subsequent increase in the desert population in future. The break down of specific power consumption in desalination, underground brackish water pumping and domestic power consumption, including transmission and distribution losses under desert energy model utilisation scenario IV, in the year 1 is estimated in Table 5.2.

Table.5.2. Breakdown of electrical power consumptions in the aquifer water pumping, brackish water desalination, domestic power consumption per day (kWh) and the calculation of total values of electrical power required per person per day (kWh),under energy model scenario IV (Ehrlic 2011, Madina 2010).

Electrical power consumption on pumping of aquifer water for drinking non drinking and cultivation per person per day (kWh)	Electrical power consumption on desalination of water for drinking an non-drinking per person per day (kWh)	Electrical power consumption on desalination of cultivation water for wheat crop per person per day (kWh)	Electrical power consumption on desalination of cultivation water for rice crop per person per day (kWh)
0.387	0.095	0.006	0.073
Electrical power consumption on desalination of cultivation water for pulses crop per person per day (kWh)	Domestic electrical power consumption per person per day (kWh)	Total electrical power consumption on pumping and desalination of brackish water and domestic power per person per day (kWh)	Total electrical power consumption on pumping and desalination of brackish water and domestic power allowing for 20% T&D losses per person per day (kWh)
0.0081	1.35	2.12	2.54

5.6. Barriers

Considerable challenges exist in the way of the implementation of the desert energy utilisation process. However, the intensity of each barrier varies accordingly. These barriers are: technological, institutional, socio-cultural and financial, which are discussed in this section.

Solar technology access from technologically advanced countries to developing energy deficient countries is limited. There are hardly any opportunities for the manufacturing of solar cells on commercial grounds in most of the developing countries. Same is the case with Pakistan. In Pakistan solar technologies are imported because of a lack of domestic technical knowledge regarding the manufacturing of solar cells and equipments in Pakistan (Khattak et al 2006). There is also a lack of maintenance facilities for these technologies, which leads to low operational reliability and customer confidence (Mirza et al 2009). The lack of a technically supportive environment could inhibit small, medium and large scale solar energy project development.

At present, there is a lack of both trained personnel and training personnel for the installation, operation, and maintenance of solar energy technologies (Khattak et al 2006). Unless an adequate indigenous skilled and semi-skilled workforce is developed, the objective of establishing a sound solar energy industry in Pakistan would be difficult to achieve (Khan 2005). Practical information regarding the installation, operation and maintenance of solar energy projects are also limited, which could prevent communities from exploring solar energy technology options (Mirza et al 2009).

Pakistan's current electric power system is designed to cater for the needs of thermal and hydroelectric power generation and supply. The infrastructure requirements of decentralized energy generation systems such as self-contained electrical power production differ from those of centralized power systems such as thermal and hydro power systems. Therefore, the existing energy infrastructure is not adaptable to support solar energy generation and supply (Khattak et al 2006)

There is also a lack of an autonomous body for streamlining the process of planning and development of large scale renewable energy projects. There were governmental organizations such as the National Institute of Solar Technology and the Pakistan Council of Alternative Technologies which were merged as a result of their inability to cooperate with each other (Khattak et al 2006). Currently, PCRET and AEDB are working on the development of solar energy projects; however, their progress is quite slow. Research and Development efforts are duplicated because of lack of information sharing and coordination between them (Mirza et al 2009). Lack of coordination and cooperation between these organisations could delay the implementation of large scale solar energy projects.

There is a considerable lack of awareness regarding the potential of solar energy and the benefits that can be accrued to communities, especially those living in rural and remote areas. Socioeconomic barriers also exist due to lack of community acceptance and compensation systems available for the installation of solar cell panels in agricultural areas (Mirza et al 2009).

Capital costs of solar energy are expensive. The relatively higher capital cost of solar equipment discourages government from opting for large scale solar power generation (Khattak et al 2006). Consequently, there is a lack of adequate financing for solar energy projects in Pakistan, particularly for medium and large scale projects, which is the outcome of a high risk perception of investment and also uncertainty about the reliability of resource assessments (Mirza et al 2009).

If these barriers are removed it is believed that it could facilitate the process of sustainable energy generation, not only in the deserts but also in the adjacent rural areas, and would bring prosperity to backward and rural areas as well as deserts. The implementation process could be started with the prefeasibility and feasibility studies of the micro and pilot desert energy projects in the desert areas. The interest and investment of existing stakeholders such as public sector electrical power generation and water treatment departments, private sector potable water, agriculture and power industries in the proposed development process needs to be stimulated by the removal of socioeconomic, technological and institutional barriers and the award of incentives. In this regard, the role of respective governments is vital by arranging subsidises, feed in tariffs and tax holidays and related legislation to encourage the investors.

5.7. Conclusions

The desert energy utilisation model is capable of meeting the energy needs of the desert communities in an environmentally sustainable and self contained manner. It is opined that a process of sustainable development based on indigenous energy sources available locally can be initiated on small, medium and large scales.

However, the resolution of technological, socio-economic barriers is essential so that the realisation of desert energy utilisation based development in the deserts can materialise. Therefore, concerted efforts are required imminently from stakeholders such as governments and private sectors, so that the quality of life of people living in and around the desert areas can be improved.

Chapter 0 6 Results and analysis

6.1. Introduction

In this section analysis on solar potential and CO_2 emissions reduction of Islamkot, Thar, Pakistan and questionnaire survey is carried out to demonstrate the capability of solar power for meeting potable water, food and electrical power needs of people living in and around the desert areas. The solar potential assessment facilitates the process of measurement of electrical power generation capability per m^2/day at the proposed desert site, Islamkot in Thar, Pakistan. The emission analysis is used to calculate the amounts of CO_2 that can be avoided if solar energy is used as an energy source in electrical power generation.

Energy and emissions analysis tools, provided in clean energy model analysis software RetScreen, 2004, are used for the calculation of solar potential and CO_2 emissions reduction amounts per. The radiation data of Islamkot, Thar, Pakistan, provided in the climate data base of the software.

The questionnaire survey is used to comparatively analyse the performance and prospects of fossil fuelled and solar powered processes. The prime objective of the comparative analysis is to gain an insight on the grey areas of the fossil fuelled processes and to evaluate the comparative advantages of solar power and desalination processes. The results of questionnaire survey are compiled and analysed in the following sections. The samples of the survey were selected from the public sector thermal power plants and private sector solar power companies.

The findings of the analysis of solar potential and CO_2 emissions reduction of Islamkot, Thar, Pakistan and the questionnaire survey reveals that considerable amounts of electrical power can be generated and carbon dioxide emissions can be avoided by the use of solar power systems. It also reveals that there are bright prospects for large scale power generation and brackish water desalination processes in the desert areas of Pakistan.

6.2. Climatic data collection for the proposed site

The climate data on solar radiation per unit area and per unit time at Islamkot, Thar, Pakistan on horizontal and tilted surface reveal higher values of radiation during summer months and lower in the winter months. The latitude and longitude of Islampur, Thar, Pakistan are measured in degrees. The heating design temperature that corresponds to the minimum temperature (-40-15ºC) is calculated on the basis of the hourly data for 12 months of the year. The cooling design temperature that corresponds to the maximum temperature that is in the range of 10-47ºC is measured on the basis of hourly data for 12 months of the year for a frequency level of at least 1% over the year.

The annual earth temperature amplitude is calculated on the basis of the difference between the maximum and minimum earth temperatures. The atmospheric pressure is calculated by using the expression, shown in equation (6.1). The relative humidity for each month and for the entire year is calculated in the climatic data base on the basis of the location of the site (Thevenard eta al 2001).

The amount of solar radiation on a horizontal surface is in the range of 0 for polar night months in the Polar Regions to 8.5 kilowatts hours per metre square per day in temperate regions during the summer months (Thevenard et al 2001). The climatic data for Islampur, Thar, Pakistan is presented in Table 6.1, and annual daily solar radiation on a horizontal and tilted scale for Islampur, Thar, Pakistan is shown in Figure 6.1.

Table 6.1 Geographical position and solar radiation availability per day (kWh/m^2) at the proposed solar phototovoltaic power generation site

Geographical position	**Islampur, Thar, Pakistan location**	
Latitude at Islampur, Thar (˚N)	24.7	
Longitude (˚E)	70.2	
Elevation (m)	43	
Heating design temperature (°C)	14.4	
Cooling design temperature (°C)	37.5	
Earth temperature amplitude (°C)	20.6	
Month	**Daily solar radiation on horizontal surface per day (kWh/m^2)**	**Daily solar radiation tilted surface per day (kWh/m^2)**
January	4.06	6.45
February	4.64	6.79
March	5.49	7.24
April	6.41	7.80
May	6.83	8.33
June	6.53	7.74
July	5.46	6.21
August	5.17	5.81
September	5.25	6.49
October	4.75	6.64
November	4.06	6.18
December	3.74	6.09

6.3. Solar photovoltaic power generation analysis

The energy analysis calculates the solar energy delivered in kWh/day, which is the amount of equivalent DC electrical energy actually delivered by the PV system to an isolated grid system. The solar potential assessment facilitates the calculation of total electrical power per m^2 per day at the proposed desert site (kWh). The total area required for the generation of estimated amounts of electrical power per person and per day is calculated in m^2 orkm^2.

The amounts of electrical power that can be generated are calculated on the basis of the amount of the solar radiation per metre square at Islamkot, Thar, Pakistan. The monthly mean values of global solar radiation on a horizontal surface, the monthly mean temperature, site latitude, PV module specifications and inverter specification are used as inputs to the energy analysis. Inverters are used in the energy analysis for the conversion of DC power into AC, which could be feed into the grid.

Array losses are included in inverter calculations. Export electricity losses, which are transmission and distribution losses in the total electricity exported to the grid, are also included in the analysis, which are 20%. The description of the solar photovoltaics system used in the analysis is given below.

6.3.1. Solar photovoltaics system description

The solar module is at the heart of the whole PV system. The PV modules can be arranged to form a solar array to produce a specific voltage and current. In the energy analysis, PV Modules of 150 Watt peak capacity comprised of mono-Si solar cells from SP are assumed. The PV modules are assumed to be fixed, that is no solar tracking, and inclined at an angle equal to the site's latitude and south facing. The azimuth angle was taken as zero for the sites.

The types of PV module considered are: mono silicon. The power capacity is an input parameter. Module efficiency depends primarily on the type of cell used in mono-Si cells. The module efficiencies vary from manufacturer to manufacturer, depending on the manufacturing processes. Therefore, manufacturer efficiency of the PV module (11.7%) is used.

In the energy analysis nominal operating cell temperature is calculated in ºC, which is the module temperature that is reached when the PV module is exposed to a solar radiation level of 800W/m², at wind speed of 1 m/s, ambient temperature of 20ºC, and no load (Thevenard et al 2001). Inverter array losses are included in the energy analysis.

The **c**alculation of the total size of desert area that would be required for the generation of the amount of energy per person per day, as estimated in table 4.2, for the purpose of meeting the needs of drinking and cultivation water and domestic power consumption per person, in a desert community at Thar, Pakistan, is shown in Table 6.2.

Table 6.2. Break down of the photovoltaics power system parameters and the **c**alculation of the total size of desert area that would be required for the generation of required amounts of energy for meeting the needs of drinking and cultivation water and domestic power consumption per person per day at Islamkot, Thar, Pakistan (RSEPA 2011)

Annual solar radiation – horizontal (MWh/m²)	1.9
Annual solar radiation – tilted (MWh/m²)	2.49
Photovoltaic	
Estimated power capacity (kW)	0.46
Efficiency (%)	11.7%
Nominal operating cell temperature (°C)	45
Temperature coefficient (% / °C)	0.40%
Solar collector area (m²)	4
Miscellaneous losses (%)	1.00%
Inverter	
Efficiency (%)	95.00%
Capacity (kW)	95
Miscellaneous losses (%)	5.00%
Summary	
Electricity exported to the grid per person (kWh/day)	2.54
Electricity not exported including (20%) T&D losses per person (kWh/day)	0.38
Net electricity exported minus T&D losses per person (kWh/day)	2.12

The electricity exported to the grid including 20% transmission and distribution losses per person day, as calculated in the needs analysis, is 2.54 kWh respectively. The total power generation capacity of the proposed solar phototovoltaic plant is calculated as 0.46 kW (460 Watts). The analysis reveals that power generation capacities can be obtained over desert areas of 4 m^2.

The scale of the electrical power generation can be increased with subsequent increases in the number of people (kWh). The size of the desert area would also be increased with an increase in the power generation capacities.

6.4. Emission analysis

Considerable amounts of carbon dioxide emissions could be avoided per day by the use of solar phototovoltaic power generation process in and around the desert areas. In the emissions reduction analysis, CO_2 emissions factor for electricity generation is used to calculate total CO_2 emissions that could be avoided in the power generation process. The emission factor is time and country specific and varies with the fuel category and country. The emission factor for the electrical power generation system is calculated in kg CO_2/kWh electrical power generation. The electricity generation CO_2 emission factor for Pakistan is 0.435 kg/kWh electric power generation.

In the emission analysis, emission factors values for the year 2005 for Pakistan are used. In the analysis, it is assumed that the proposed solar system would facilitate in avoiding the volume of CO_2 emissions equivalent to the volume of emissions that would have been released by a base case fossil fuel power system in the generation of same amount of electrical power (Thevenard et al, 2001). The solar phototovoltaic power generation system is presumed as the CO_2 emissions mitigation option in emission analysis. The net amounts of emissions that can be avoided are calculated by the multiplication of emission minus the electrical power lost in transmission and distribution losses. The total amount of CO_2 emissions (kg) that can be avoided per person per day because of the use of solar photovoltaics power generation process are shown in Tables 6.4.

Table 6.3 Break down of amounts of CO_2 emissions produced by a fossil fuelled power generation per person per day (kg) and net amounts of CO_2 emissions (kg) that can be avoided pert person per day because of the use of solar phototovoltaic power generation processes (REA2011).

Base case system CO_2 reduction summary			**Fuel consumption in power generation per person per day (kWh)**	**CO_2 emission factor (Kg)**	**CO_2 emissions produced on power generation per person per day (Kg)**
Fuel type	Fossils				
Electricity	100.00%		2.54	0.435	1.10
Total	100.00%		2.54	0.435	1.10
Proposed case system CO_2 summary (Solar power project)			**Fuel consumption (kWh)**	**CO_2 emission factor (Kg /kWh)**	**CO_2 emission avoided on solar power generation per person per day (Kg)**
Fuel type	Solar energy				
Electricity	100.00%		2.54	0.000	0.0
Total	100.00%		2.54	0.000	0.0
CO_2 emissions lost due allowing for 20% T&D losses while exporting electricity to the grid per day	(kWh)	0.50	2.54	0.435	0.220
CO_2 emission reduction summary Solar photovoltaics power project	**Base case CO_2 emission on fossil fuel power generation per person per day (Kg)**	**Proposed case CO_2 emission per person per day (Kg)**	**Gross CO_2 reduction on solar power generation per person per day (Kg)**	**CO_2 credits transaction fee %**	**Net emission avoided on solar power generation per person per day (Kg)**
Net annual CO_2 emission reduction	1.10	0.220	0.87	2%	0.70

The environmental emission assessment results reveal that net emissions of 0.70 kg of CO_2 could be avoided per person per day entering into the local atmosphere, if solar power generation process is used instead of fossil fuels. The results are promising for a developing country, which is a signatory of the Kyoto agreement and is looking towards reductions in the existing emissions levels. Kyoto is a legally binding agreement between signed-up countries to meet emissions reduction targets of all greenhouse gases by 2012 relative to 1990 levels.

The amounts of the emissions that could be avoided would bring positive results to the desert environment. There are also financial implications of emissions reductions in terms of the savings of emission neutralisation costs, otherwise incurred in the use of carbon separation and sequestration. Considerable amounts of revenue, therefore, can be saved by the use of solar power generation supply systems.

6.5. Bi-product salt production

Salt can also be obtained as a by-product in the process of desalination of underground aquifer water. The amounts of salts (kg) that can be obtained are based on the amount of backscatter desalinated that would be consumed (m^3) per person per day. The amounts of brackish water salinity are calculated on the basis of the salinity levels (ppm) that exist in parts per million in the underground water at the Thar Desert (Rahamoo 2011).

The salinity level (kg) is multiplied by the amount of desalinated water to obtain the total amounts of salts. Salt is a useful commodity and has domestic, commercial and industrial applications. The calculation of revenues is based on the per 10^3 kg prices of the salt for the year 2011. Small amounts of salts would be available per person per day. However, these quantities could increase by an increase in the number of persons in desert community

Break down of the amounts of salts that can be produced per day (10^3 kg) and total amounts of revenues (US$) that can be generated per day, assuming a salt price of $20 (USD) for each 10^3 kg is illustrated in Table 6.4.

Table 6.4. The calculation of the amounts of salt that can be produced per person per day (10^3 kg) and specific amounts of revenue that can be generated per person per day, assuming a salt price of $20 (USD) for each at the proposed desert site, Islamkot, Thar, Pakistan (Rahamoo 2011;Zaigham 2001)

Total brackish water desalinated per person per day (m^3)	Total dissolved salts (ppm) per m^3 of brackish water desalination (kg)	Electrical conductivity of aquifer brackish water (µS/cm)	Estimated salt production from desalinated water quantity required per person per day (10^3 kg)	Expected revenue from the recoverable salts per person per day (US$)*
0.387	0.0027	4000.00-5000.00	0.0010	0.020

*= Salts prices for the year 2011 are used in the estimation of revenue.

Since the amounts of salt that can be produced per day are small, it is presumed that it would be consumed by the people living in and around the desert areas. However, revenue can be generated by the sale of surplus salts in case of the large populations. However, the scale of salt production could be extended in future with corresponding increases in the desalination water production capacities.

6.6. Questionnaire survey

The questionnaire survey on power generation and desalination processes is carried out by the author to obtain information on the existing water treatment and power generation processes and to compare them with the solar power desalination based water treatment processes. The samples were taken from the water and power industries and an academic institute, with the aim of evaluating the feasibility of the solar powered electrical power and desalination systems. The format of pilot questions and questionnaire survey are attached in appendix A. The main questions in the survey are on: the nature and volume of input energy consumption, the amount of environmental emissions, the size of production costs and the percentage of environmental sustainability.

In total, 12 questions were asked to obtain their opinions, suggestions and recommendations regarding energy consumption, costs ranges, emissions' volumes and environmentally sustainable power generation and water treatment processes. The response rate of the questionnaire and pilot question is 40%. The overall impression of the respondents is encouraging on account of the availability of solar energy potential, the clean nature of energy generation and zero fuel costs. The results of the survey are produced and analysed in the following sections.

6.6.1. Potable water production

The prime objective of the survey on existing water treatment processes is to analyse comparatively the processes of solar powered and fossil fuelled water desalination and treatment processes. The analysis is based on the main variables of the volume of energy consumptions, volume of CO_2 emissions, the range of operational costs and the nature of the input water.

The survey results of fossil fuelled and solar powered potable water production process are analysed comparatively to find out whether solar desalination systems can be used alternatively for the production and supply of potable water in deserts in an effort to overcome the drinking and non-drinking water shortage. The findings of the questionnaire survey from the respondents are furnished below.

6.6.1.1. Input sources and energy consumption

In the survey, the respondents reported that the input of seawater could be used as a reliable input for the desalination process because of its accessibility for large scale desalination. It was also stated that brackish underground water could be considered a reliable desalination process input in the deserts. The amount of electrical power consumption per m^3 potable water production rates of the surveyed solar power companies are illustrated in Figure 6.1

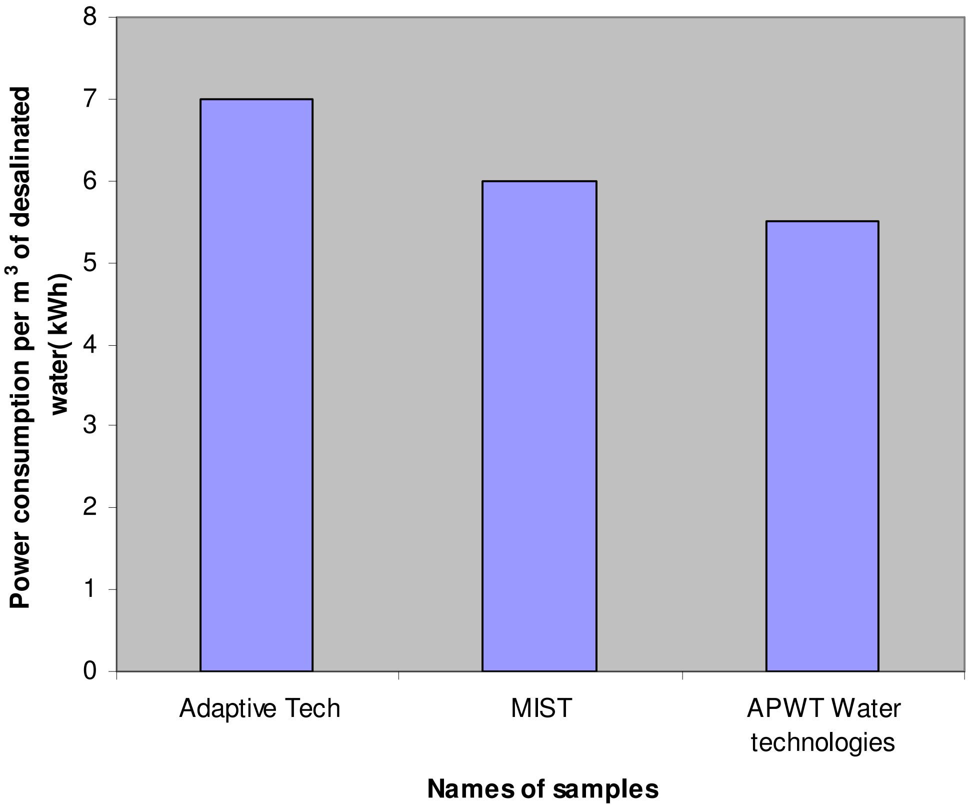


Figure 6.1.Electrical power consumption per m^3 of desalinated water

The existing power consumption levels, provided in the survey were in the range of 5-7 kWh for the production of per m^3 of potable water production, which were more than the power consumption used in the proposed solar powered reverse osmosis process. It reveals the importance of the use of reverse osmosis process in the desalination processes.

6.6.1.2. Environmental emissions

It is stated by the survey respondents that fossil fuelled potable water treatment and desalinat6ion processes causes considerable damage to the environment, as these processes are accompanied by the burning of fossil fuels, which produce CO_2 emissions. The amounts of CO_2 emissions that could be released to the environment per m^3 of potable water production, as responded in the survey, are shown in Figure 6.2.

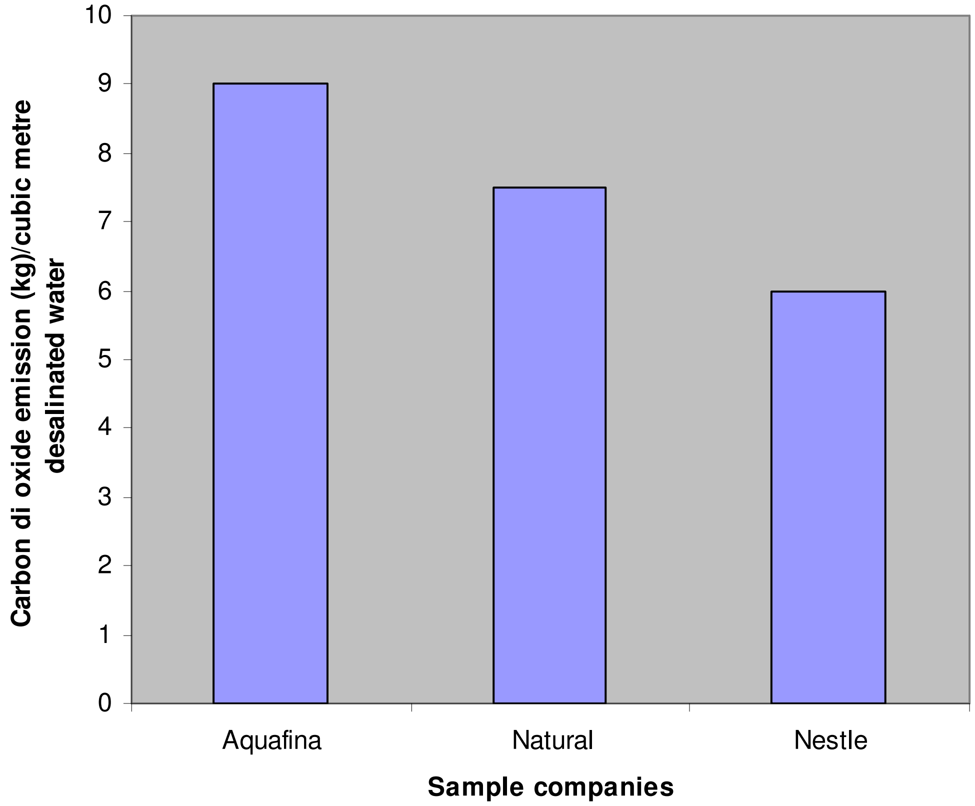


Figure 6.2. Amounts of CO_2 emission releases per m^3 of desalination in existing processes

It was responded that the carbon dioxide emissions level varies from 6-9 kg/m^3 of potable water desalinated. Realisation exists amongst them about the burden of environmental costs, and the use of solar powered desalination processes was considered a potential alternative to the fossil fuelled desalination systems.

6.6.1.3. Production costs

The survey respondents stated that the production cost optimization process is an important aspect for the potable water production. According to them, the high operational fuel and maintenance costs of the fossil-fuelled processes are a matter of concern for the stakeholders in the water industry. However, these costs can be optimised by the use of a solar powered desalination process due to zero running costs and negligible environmental neutralisation costs. The total power generation costs are the sum of the operation, transmission, disposal and emission neutralisation costs. The volume of costs used in the fossil fuelled and solar powered water treatment processes, as reported by them, are illustrated in Figure 6.3.

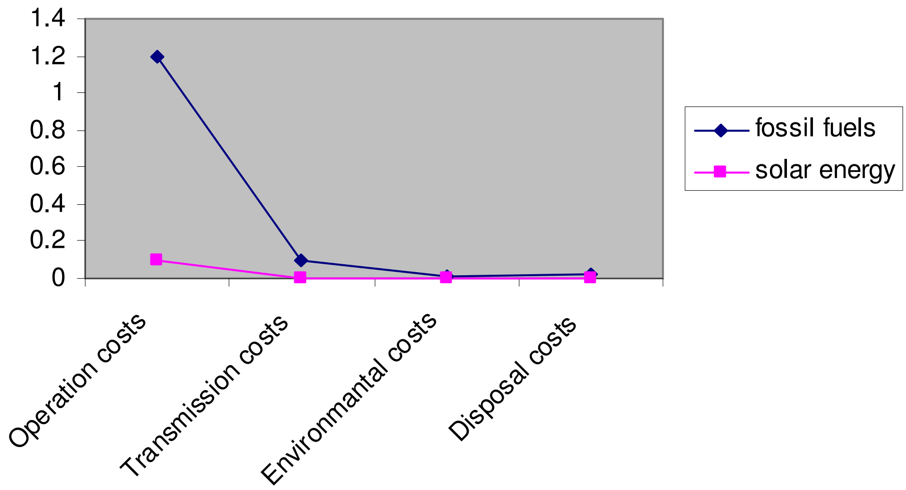


Figure 6.3. Break up of desalination costs in existing desalination plants

The total costs of fossil fuelled and solar powered potable water production processes, as reported by the survey respondents, are given in Figure 6.4.

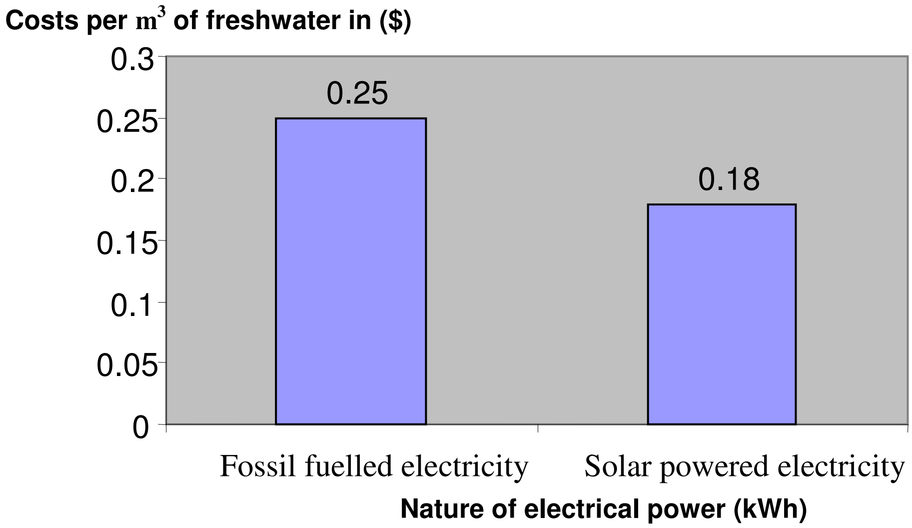


Figure 6.4. Costs comparisons of fossil fuelled and solar desalination processes

However, a broad agreement exists among the solar desalination company professionals regarding the feasibility of the reverse osmosis solar desalination water treatment process on account of the lowest power consumption per m^3 of potable water production.

6.6.1.4. Environmental sustainability of solar desalination

The sustainable nature of the solar desalination process was valued on account of the clean nature of the solar energy. The solar powered desalination systems are considered environmentally sustainable by the survey respondents. Environmental sustainability ranges, as contemplated by the respondents, for solar desalination processes are illustrated in Figure 6.5.

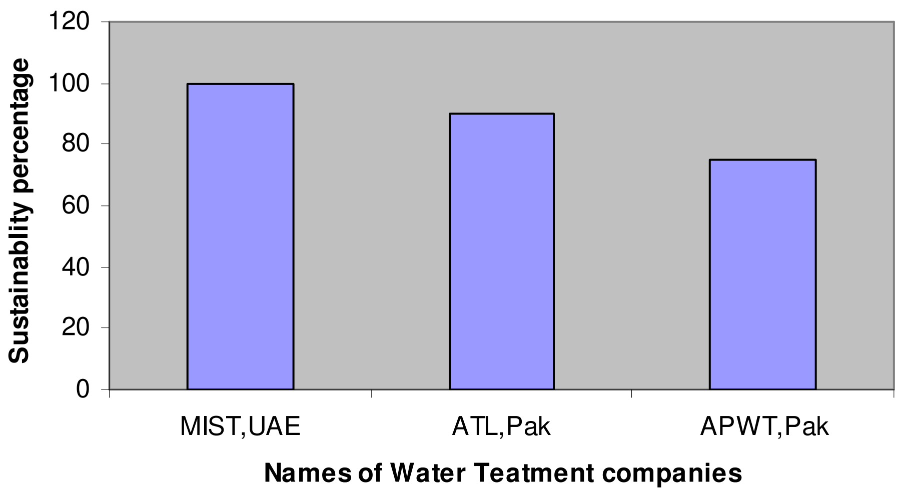


Figure 6.5. Environmental sustainability for solar desalination process

6.6. 2. Electrical power production

The objective of the survey of existing electrical power generation processes was to analyse comparatively the processes of solar powered and fossil fuelled power generation and supply systems. The survey included the main variables of input energy consumption, volume of emissions, ranges of costs and environmental sustainability. The thermal, hydroelectric and solar photovoltaics power generation processes were covered in the survey. The samples were taken from thermal power plants and solar power companies of Pakistan.

The results of the survey samples revealed their agreement on the limited nature of fossil fuels and the capability of the solar phototovoltaic power generation plants in meeting the energy needs of present and future communities in an environmentally sustainable manner.

6.6.2.1. Input source and energy consumption

It was informed in the survey that 3600-8370 kJ energy being consumed in the generation of 1kWh power electricity in oil powered steam, gas turbine and combined cycle power generation plants, and 21600-25200 kJ solar radiation is required for the generation of 1 kWh solar powered electrical power. The amounts of solar energy required (kWh) to produce 1 kWh electrical power, as reported are given in Figure 6.6.

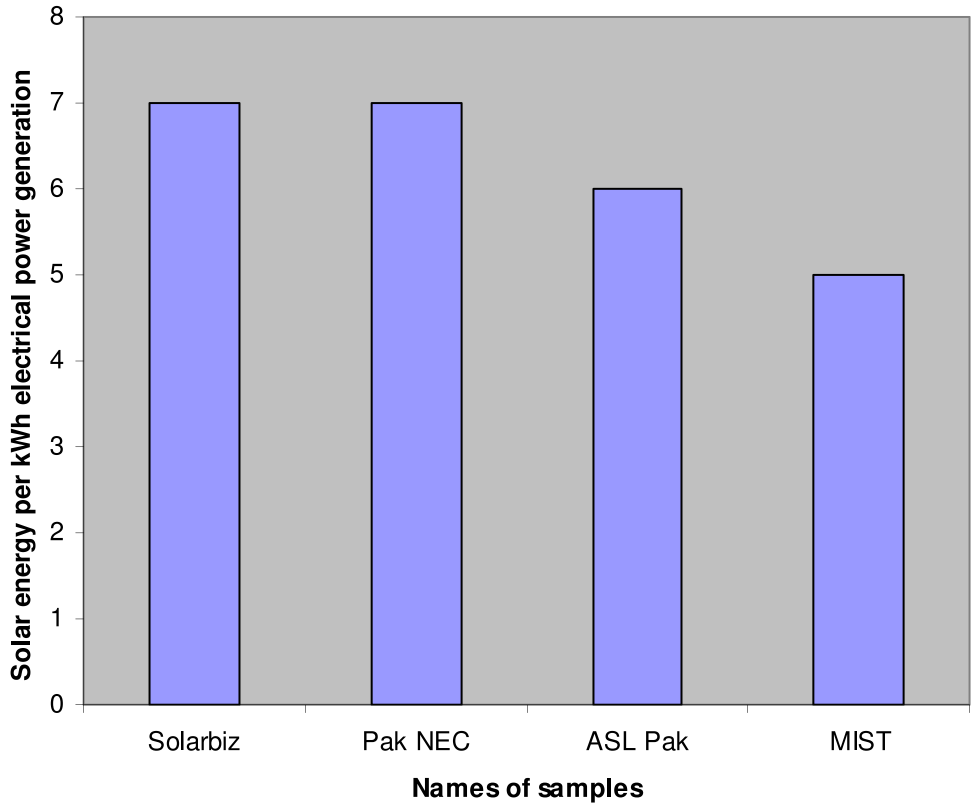


Figure 6.6. Anticipated solar energy consumption (kWh) per kWh electrical power generation

6.6.2.2. Environmental emissions

It was stated by the survey respondents that due to the carbonized nature of coal, oil and natural gas the emissions of CO_2, CO, air pollutants like NO_x, $SO_{x,}$ particulate matter, and smog are produced in thermal power plants during their operation. It was also reported that the levels of these emissions are increasing to an alarming scale, and could only be decreased by the use of non carbon fuels such as solar technologies. It is revealed by them that approximately 1.75-2.00 kg CO_2 emissions are emitted per kWh electricity generation in fossil fuelled power plants. The levels are even higher in coal powered electricity generation because of highest level of emissions releases. The amounts of emission release per kWh electrical power generation in thermal power generation, as reported by the survey respondents, are illustrated in Figure 6.7.

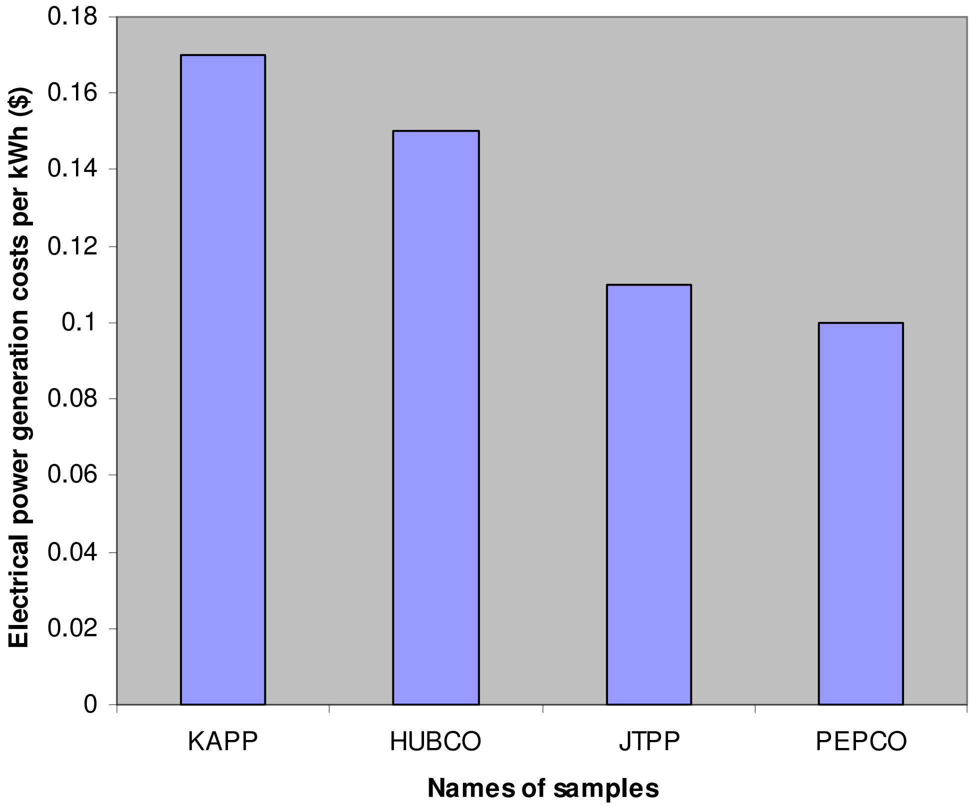


Figure 6.7 The amounts of emission releases per kWh electrical power generation in thermal power generation

6.6.2.3. Production costs

It was believed by the survey respondents that due to the global increase in crude oil prices, the prices of thermal electricity were increasing continually and forecasted a likelihood of fossil fuelled electricity costs rising to twice or thrice the current oil prices. It was also held by them that the effect of these rising costs could be neutralised through the use of solar photovoltaic or solar thermal power plants. Though the capital costs of solar power are higher than the fossil fuelled power plants, fuel and maintenance costs of solar power are negligible, which is valued by them. The costs of thermal powered electrical power in Pakistan are shown in Figure 6.8.

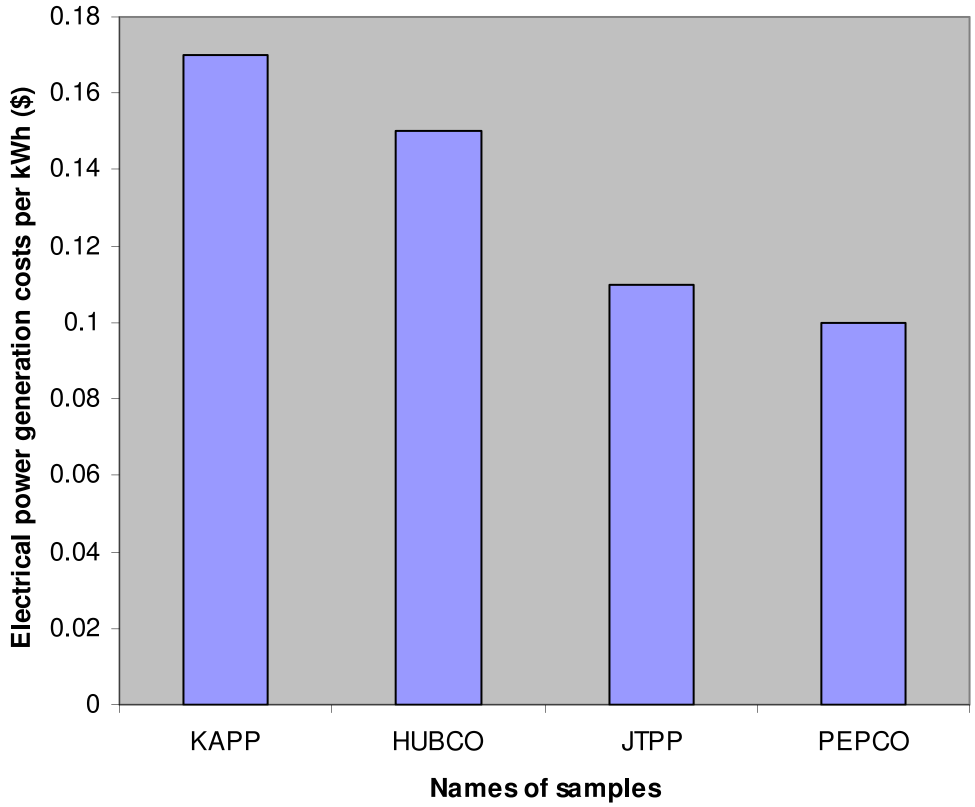


Figure 6.8. Thermal electricity generation costs per kWh.

It was believed by the survey respondents that the solar panels being fuel free and require fewer maintenance jobs over the whole period of their life. It was also reported by them that capital costs of solar power generation plants could be decreased by the award of subsidies to domestic and commercial consumers, and the solar power plants costs could be recovered in small span of solar equipment's life through the sale of electrical power to the commercial and industrial sectors. The existing range of solar electricity generation costs, as reported by the survey respondents, is highlighted in Figure 6.9.

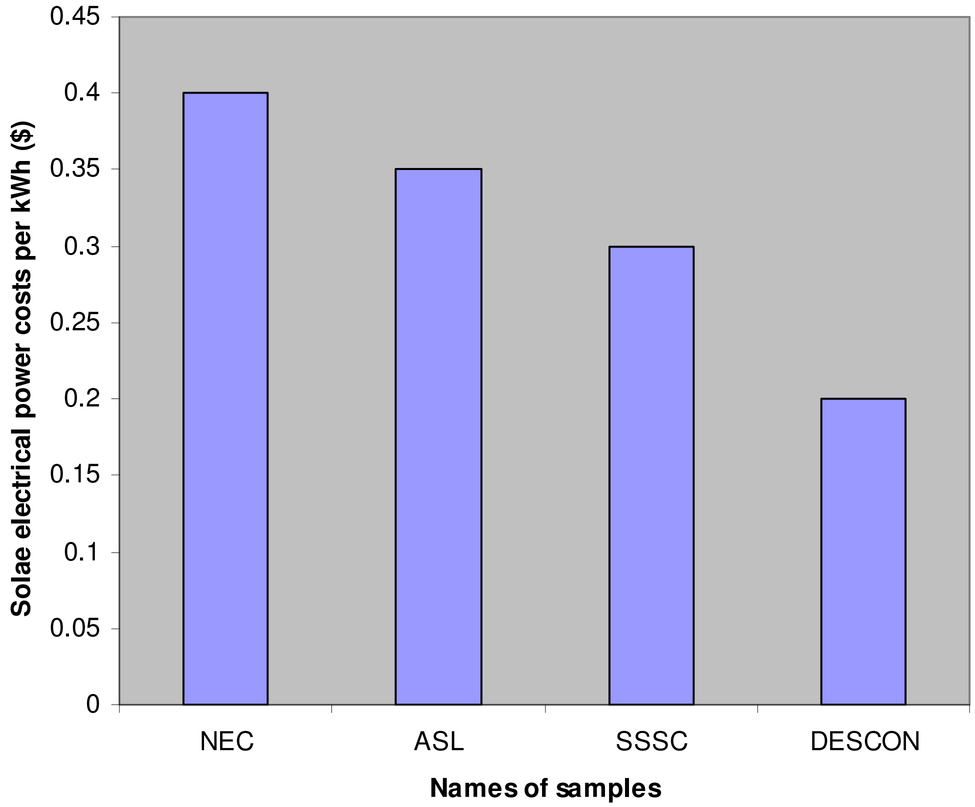


Figure 6.9. Anticipated solar electricity generation costs

Solar electricity was also viewed by the thermal power industry respondents as an economical choice. It was presumed by the academic researchers in MIST that the prices of solar electricity could be as competitive when the prices of oil constantly reaches above constantly above US $100/ barrel, which was anticipated for the year 2020, and according to them in that case, the prices of solar energy and fossil fuels could be the same.

6.6.2.4. Environmental sustainability of solar power generation

It was reported by the survey respondents, solar power plants were considered more sustainable environmentally than fossil fuelled power plants on account of the release of a negligible amounts of anthropogenic emissions. Environmental sustainability level given by the solar and thermal power survey respondents are illustrated in Figure 6.10.

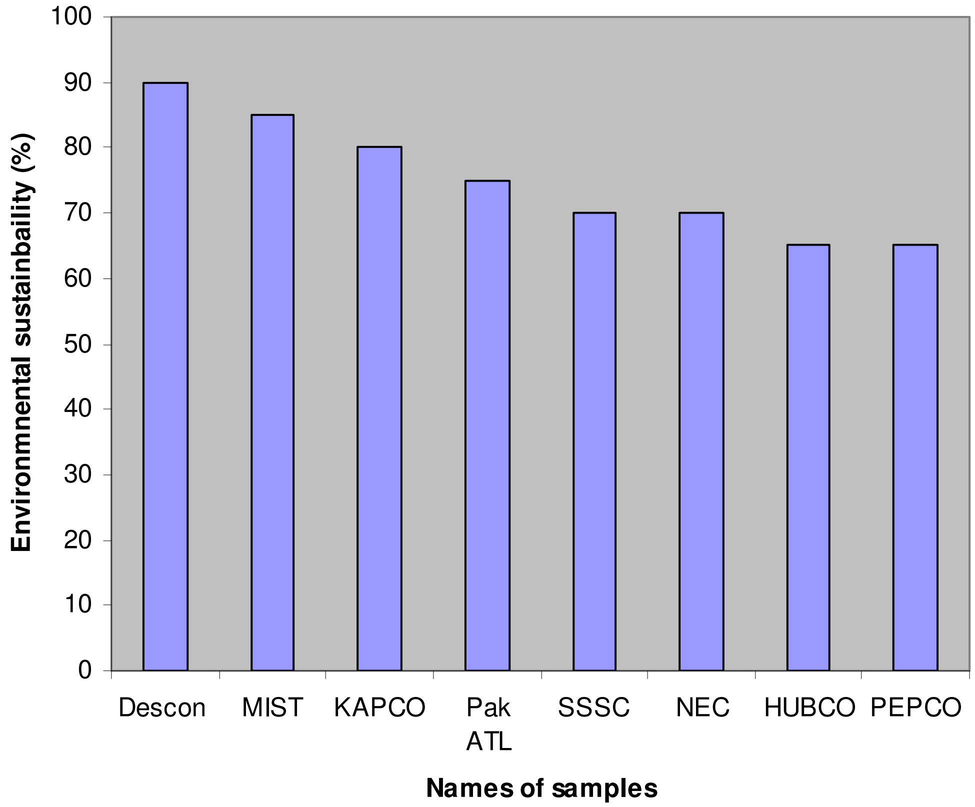


Figure 6.10 Environmental sustainability for solar power generation process

It was believed by the thermal and solar power survey respondents that bleak future prospects of fossil fuelled power generation in comparison to solar power generation on account of their limited quantities and release of CO_2 emissions. It was also believed by them that solar energy in solar rich countries could be utilized reliably to enhance existing electrical power generation capacities.

6.6.3. Analysis on questionnaire survey results

Of the three water treatment processes that are used currently, including water softening for removing hardness, water deionization for demineralization from water, the purification process for filtration and test development the reverse osmosis process was considered by the survey respondents more efficient and economical in the long run due to less power consumption, especially in multi effect desalination processes due to higher efficiency rates.

It was believed by the thermal and solar industry respondents that since fossil fuelled desalination processes not clean, and being accompanied by CO_2 emissions, the solar desalination process would emerge a better option in future.

Solar desalination systems were also considered clean environmentally and practicable for supply of drinking water to far flung areas including deserts. Solar power generation grid tied solutions and solar desalination processes for desalination of brackish water were considered self contained.

Fuel, distribution and maintenance costs of oil, coal and natural gas powered plants were also considered, by the survey respondents to be high. According to them, fossil fuel costs were increasing continuously and there was likelihood of a further decrease in their prices. It was also reported that the share of solar electricity generation could be increased substantially in future, no matter how slow it is.

Solar power generation processes were, however, criticized by thermal industry engineers on account of expertise and off-solar hours. The world's largest solar plant with a 354 MW capacity spread over an area of 1600 acres was criticised by them on account use of large area of land. However, it was recognised by them that the cost was not the only criteria. According to them, solar electricity option could become a better option for the supply of electrical power to small populations.

Environmentally, fossil fuelled thermal power plants were considered by the respondents unsustainable because of the release of considerable volumes of carbon dioxide emissions. The capability of fossil fuelled power plants to meet electricity needs in the long run, according to them, was questionable and unfeasible. The precedent of the UAE was highlighted on account of their success in the use of solar energy, and their strategies of arranging capital by the sale of indigenous oil and gas reserves.

6.7. Conclusion

The energy analysis findings reveals that available solar energy potential is capable of producing the required amounts of energy for meeting the potable water and electrical power needs per person per day over the utilisation of 4 metre square desert land area, which is manageable.

The results of the emission reduction assessment reveal that the considerable amounts of fossil fuel can be saved per kWh of solar power generation per day and these quantities can be increased by subsequent increase in the scale of electrical power generation in the long run.

The questionnaire survey results analysis supports the proposition that the solar power generation and potable water production processes are feasible economically and environmentally, on account of their release of negligible amounts of CO_2 emissions. The prospects of solar powered power generation and potable water production are held bright in the short, medium and long term.

Chapter 07 Discussions

7.1. Findings

The solar potential analysis of the proposed desert area reveal that the objectives of meeting the energy needs of communities living in and around the deserts could be attained by the utilisation of solar powered self-contained solar power generation systems in environmentally sustainable manner. The potential advantages that can be accrued from the proposed development are considerable, and are bound to leave positive impacts on the social, economic and cultural sectors. Micro level results are obtained and the scales of development can be enhanced to cover rural areas as well.

The discussions on stretching of research results and possible barriers in the implementation of proposed development are also discussed to raise awareness in the stakeholders including desert communities, local government and the public and private sector power and potable water producers. It is believed that concerted efforts are required to stimulate their interests in the development of solar powered self contained energy generation and supply system. The possible measures and recommendations that are essential are also discussed to streamline the process of sustainable development in and around the desert areas of Pakistan.

Above all the discussions on the how the objective of enhancement and diversification can be attained and how to widen the scope of research to stimulate the future researchers to come forward and to contribute in the further to develop further these areas in the long run. At this stage it would be useful to discuss briefly about the level of success in the attainment of research objectives that is obtained at this stage.

7.2. Solar capability of meeting the total needs of a desert community

The solar energy analysis reveal that the basic needs per person per day in a desert community could be fulfilled sustainably in an environmentally friendly and self-contained manner by utilisation of $4m^2$ desert area. It includes the needs of drinking, non drinking and cultivation water, electrical power and wheat, rice and pulses needs of these people. It is believed that such approach would improve the quality of life of the people living in and around the desert areas without movement to other areas. Such development process would provide socioeconomic stability ultimately in these areas in the long run.

However these communities are dynamic and the scope and volume of their needs could be diversified in future, for which allowances could be provided to the total amount of estimated energy requirement to accommodate future energy needs of these communities.

It is believed that the experience gained in the desert areas can be applied to the adjacent rural areas of Pakistan for the development of small, medium and large scale solar power generation and desalination. It is expected that the fruits of modernisation and divergence in the solar energy technologies would further contribute to the process of sustainable development in isolated and backward areas of Pakistan.

In light of the pace of development that can be attained in these areas it can be said that there are bright prospects for growth in the underdeveloped desert and rural areas of Pakistan. It is a fact that solar energy is renewable and is not prone to depletion. Therefore, it can be said that that solar energy powered system would be capable of meeting the energy needs of future increases in the populations of desert and rural communities reliably by the utilisation of solar energy and ultimately the needs of industrial and commercial sectors in the long run.

7.3. Large scale power generation and desalination

It is opined that a network of large scale water and power generation processes can be established in and around the desert areas and the rural areas of Pakistan to accommodate electrical power and potable water needs of the people living in and around these areas. The process would discourage the use of fossil fuels in power generation and potable water industries and could establish a system of solar energy utilisation.

A system of decentralised energy generation and supply systems would also be established and the share of fossil fuels in the energy supply mix could be decreased in the long run. The process would serve the purpose of environmentally sustainable development in the majority of rural areas of Pakistan. Decentralised energy system infrastructural facilities could also be used to diminish prevailing backwardness in desert and rural areas.

7.4. Socio-cultural and economic stability

It is believed that the objective of reclamation of barren desert land and positive changes in local agrarian economy at these deserts can be attained. The process would facilitate the process of stopping migration of the people living in and around these desert areas of Pakistan, and a process of building a local economy in the deserts can be streamlined in the long run.

It can be expected that due to solar powered development the socioeconomic problems of land dryness, frequent drought and impending poverty would be diminished. It is proposed that the costs of solar power plants could be borne from the developmental budget programmes and regional aid programmes. This would have the benefits of rehabilitation and socio-economic well being of people of not only desert areas but also of rural areas of Pakistan communities. It is believed that such development would be accompanied by an improvement in the human development index of desert and rural areas and an increase in the agricultural outputs.

It is also expected that nomadic and semi nomadic life culture would be diminished gradually in these deserts when the required quantities of potable water, food and electrical power would be made available on their door step. It would encourage local people to think beyond the problems of socioeconomics and would stimulate them to work for larger interests such as the development of communities and nation building.

7.5. Environmental sustainability

The availability of solar powered electrical power would discourage the people living in these areas of the use of dung and wood, which are used currently for meeting the needs of lighting, heating and cooking, which are sources of continual increase in anthropogenic emissions levels. It is believed that solar powered process would facilitate subsequent reduction in the amounts of environmental emission levels. Such development would also facilitate a process of environmental and ecological conservation.

It is opined that the solar powered development process would ultimately bring about a green revolution in and around the desert areas of Pakistan. It would also discourage the practice of cutting trees and the burning of wood, which are the prime reasons of deforestation and environmental emissions degradation. However, the role of environmental agencies is vital in the development of legislation and incentives on the use of non-fossil fuels in these areas.

7.6. Feasibility of desert energy utilisation model scenarios

The solar energy analysis reveals that desert energy resources utilisation process is feasible for the development of desert and rural areas of Pakistan. It is believed that the amounts of these desert resources such as low opportunity cost desert land, underground aquifer brackish water and high radiation solar energy are capable of initiating a process of sustainable development in these areas.

It is opined that people living in and around the desert areas, which are prone to hunger and thirst would benefit ultimately from a sustainable solar power and desalination process. It is also believed that it would diminish ultimately the curse of droughts in these areas and loss of men and materials.

7.7. Prospects of large scale solar power utilisation in the deserts of Pakistan

The process of desert power generation has gained momentum with the passage of time. It is believed that small, medium and large scale solar power generation and desalination process could be successfully used in attaining the objective of meeting the energy needs of the communities both living in the deserts and adjoining rural areas of Pakistan. Feasibilities studies carried out on the use of large scale solar power generation in the desert of Pakistan support this proposition. The findings of the studies are encouraging and shows that there is a great potential for large scale solar power generation systems in Pakistan (Rasool 2010)

It is opined that since the energy needs of Pakistan are multiplied over the time, it is high time to launch large scale non-fossil fuelled energy projects in the desert areas of Pakistan. In this regard it is proposed that Pakistan Desert Power Utilisation Project (PDPUP) under a strategic partnership between the Pakistan Electric Power Company, the Alternative Energy Development Board and the Pakistan Council of Renewable Energy Technologies can be worked out. The project can facilitate the production of non-fossil electrical power generation and the desalination of underground aquifer water in the deserts. Electrical power and potable water are much demanded and surplus amounts of these commodities can be transported to other areas of Pakistan.

Technically, a considerable amount of power can be transported on DC transmission lines over very long distances in the form of three phases alternating, as is transported in the European high voltage area (WPI 2006). However, between the areas separated by water, a direct current transmission submarine cables system is used to transmit electrical power. Direct voltage can be used especially for long transmission lines because it results in lower losses and economic advantages (Meisen and Pochart 2006). However, DC transmission system is used to transmit electrical power over 1000-km distances (MacKay 2008). High voltage direct current (HVDC) have the advantages over traditional HVAC lines because of less physical hardware, less land area, electric network stability and small power losses. There are losses in high voltage AC-systems up to 15 %/1000 km for 380 and 8 %/1000 km for 750 kV power capacities respectively, and each transformer station can lose 0.25 % of the energy (WPI 2006).

If the construction of PDPUP is given priority, a process of large scale power generation and potable water desalination could be started in and around the deserts areas of Pakistan. The ultimate results of desert power generation would be: huge power generation capacities, security of energy supply, diminishing dependence on fossil fuels and a reduction of greenhouse gas emissions. The scale of operation of PDPUP project could be increased to remaining desert areas of Pakistan to accommodate increasing electrical power demand of the people living in rural and cities of Pakistan.

Large scale solar power generation processes are successfully carried out in the neighbouring countries to Pakistan. The Gobi desert project in China, which was planned to cope with the rising power needs of their growing population, is quite successful in attuning these objectives. The proposed project included the construction of 139 solar power plants of 100 MW at different locations between 2001 and 2020 in the Gobi desert (Meisen and Pochart 2006).

It is estimated that each station would cost around $ 84 million to build, and the total investment for the construction of 139 stations would cost about $ 200 billion (Meisen and Pochart 2006). It is also estimated that it could pay back the investment in 2020. The estimated profit in 2020 is roughly $1.2 billion (Meisen and Pochart 2006). The assumed value of electricity per kWh is in the range of US$ 0.18-027, and the expected share of displacement of fossil fuels by the year 2020 would be in the range of 20-25% (Enebish 2009). Since Pakistan and China enjoy a good relationship, it is proposed that bilateral agreements on the generation and supply of large scale solar power generation in the deserts and rural areas of Pakistan should be signed, to initiate the process of desert solar power generation.

Socioeconomic development process in the deserts based on solar power generation could be attained similar to those found in Masdar, which is one of the most sustainable cities in the world, at approximately 6 km^2 in area, which is also a global clean-technology cluster (Masdar 2011). In Masdar city the energy needs of 40,000 residents and hundreds of businesses are met by a range of renewable energy and sustainable technologies, across the living and working community in there. There is the likelihood of establishing a solar energy powered development process in the deserts of Pakistan in an effort to bring them on par with the towns and cities.

Since all these achievements based on solid initiatives are target oriented, it is essential to set up the objective of producing 10% of the total energy from solar power in the deserts, as was done in Masdar. UAE, by setting a goal of generating 7% of its energy needs from renewable sources (Masdar 2011).

A complete life-cycle analysis of the PDUPP would be required thoroughly, to study the volume of electrical power that could be generated at various phases of the project and the amount of carbon dioxide, which would be avoided per day during the operation of the proposed solar power generation processes. A life cycle costing process of the proposed solar power generation and desalination plants would be required to facilitate a process of prediction of life cycle costs including the costs of the acquisition of equipment and maintenance throughout its life. A life cycle cost plan would also provide the stakeholders with a clear understanding of the life cycle costing requirements and methods in all the stages of the proposed solar power plant. Risk assessment processes are also included in the life cycle assessment process.

7.8. General issues pertaining to the success of the proposed project

It is opined that there are general issues associated with the implementation phase of the desert resources development process. Though the analysis of these issues is beyond the scope of the current research due to time constraints, these are important and should be taken care of at the implementation stage. A brief description of these issues is carried out in the following sections.

It is believed that the wastage of the produced commodities needs to be discouraged by putting a limitation on the usage capacities. Since there is likelihood that more quantities of potable water and electric power could be required at later phase, the process of planned expansion for the existing capacities of power and potable water would be required. An increase in the production of the commodities mentioned each year could accommodate the growing population needs. However, funds should be allocated in the development budgets to cater for a phase wise expansion in the electrical power generation and potable water production capacities.

It is opined that in order to preclude the possibility of food shortages due to increased demand and low agricultural yield certain allowances would be required each year to meet such exigencies, although the use of advanced agricultural methods would increase the yield and would sustain the additional demand for food.

It is believed that a process of diversification in the production of food commodities such as the breeding of fish, meat and cultivation of fruits would also supplement the existing food reserves. It is also opined that the use of rationing cards could enable the administration to maintain a record of food consumption and to maintain a balance between the commodities demanded and supplied.

It is also opined that a gradual increase in the production capacities of drinking, non-drinking and domestic power consumption would be required to meet the needs of a growing population in the future. Therefore, a periodic increase in the potable water production and electrical power generation capacities would be required to neutralise the possible future shortages of drinking, non-drinking and cultivation water.

It is believed that the rainfall water can be stored in cemented storage tanks that can be used for a few months for the animals. Moreover, waste water drained in underground storage can be recycled through the desalination process to make it fresh. It would serve the purpose of a reserve that could be reprocessed continually.

The recycled waste water in underground storage tanks can be used for non drinking jobs such as flushing, cleaning and agriculture and could optimise the water demand. A centralised and separate filtration process can be installed in the houses' drainage outlets, allowing the filtered water to be exposed to the sun in large bottles for treatment so that a hygienic colour and acceptable taste for the water could be attained.

7.9. Potential advantages

Many advantages would be accrued by the utilisation of the desert resources, which are described in the following section. These advantages would bring the desired results of sustainable development in social and economic sectors.Sustainable development in the deserts could lead to the development of commercial units and cottage industries in the deserts. The availability of inexpensive labor plus availability of electrical power could attract the local investors to these areas.

Though Pakistan is an agrarian country, self-sufficiency could not have been attained due to the problems of land barrenness, water logging, salinity and low agricultural outputs. The availability of water could facilitate cultivation of food crops. The process could be expanded to adjacent rural territories, which are without agriculture due to water scarcity.

It is believed that the supply of water to these areas would facilitate the process of tree plantation and agriculture. Therefore, the desertification process could be controlled to a greater extent. The power and potable water industries can be stationed in these deserts to resolve power and water supply problems. A considerable portion of the labour force could be employed in the cultivation of food and cash crops. Since a major portion of unemployment is due to unemployment of lack of utilization of labor in agriculture sector, the unemployment rate could ultimately be diminished with the reclamation of desert land ultimately. A human resources development process could be launched by the agricultural, commercial and industrial enterprises in order to impart the latest skills and tools to the labour force in the long run.

It is opined that a positive environmental impact would be realized for the human and animal population. The green grass that is the fodder of animals would be made available in the desert areas. The solar photovoltaic power is a clean energy source, and it would be used to avoid the release of CO_2, NO_2 and SO_2 emissions into the environment every year.

7.10. Conclusion

The preceding discussions on research results lead to the conclusion that the objectives set are attainable, and the desert resources utilisation process can be launched on large scale in the desert areas of Pakistan. There fruits can be borne for the good and welfare of the people living in and around these areas. An exciting feature of solar powered sustainable development process is that the scale of the development processes can be extended in future to accommodate future energy needs of desert and rural communities.

However, there are financial, infrastructural, socioeconomic and technical problems in the realisation of the solar powered sustainable development process, which need to be resolved amicably, with the participation of stakeholders, as specified in the preceding sections.

Chapter 8 Conclusion and recommendations

8.1. Introduction

The worth of the desert solar energy utilisation process is established in the sections on findings and discussion, on account of its positive contribution to the supply of basic needs to the people living in and around the desert and rural areas of Pakistan, prospects of anthropogenic emissions avoidance and sustainable development process, plus the fact that it would provide a path for a gradual switchover from fossil fuels to renewable energy sources.

It is believed that the proposed process could establish an energy generation system in and around the desert areas, and would overcome the ongoing energy crisis in the country, which has badly affected the domestic, commercial and industrial sectors in the country.

In this regard, it is advised to seek technical support either thorough collaboration with solar technology advanced neighbouring countries, which have launched successfully similar projects in their countries. It is established in the preceding analysis that in future it would be preferable to generate power in the desert and to use it for meeting energy needs of the desert communities and to export the surplus amounts to the rural areas and cities.

However, in the transition process certain steps would be to encourage the investors to look towards larges sale power generation processes in the deserts. Therefore incentives, subsidies, feed in tariffs and tax holidays are required to encourage the investors to adopt solar technology based commercial and industrial systems. In this regard, the role of the both local and national government is of prime importance in the allocation of lands, infrastructure and security to the personnel and their materials within these desert sites.

It is opined that it would lead ultimately to the path of self-sufficiency in the energy sector. The provision of sustainable energy supply would ultimately boost the process of development in the domestic, commercial and industrial sectors. It is believed that the lives of communities living in and around these areas would be improved. The process of sustainable development in the deserts would have a direct impact on the expansion in the existing energy capacities.

However it is opined that continual geological and agricultural research would be useful. The research on the quantity and quality of underground aquifer water, soil fertility and the types of rotational crops should be carried out independently, with the objective of replenishing the underground water reservoirs and improved productivity levels.

In this regard it would be advisable to establish coordination with the agricultural research institutes regarding the testing of soil fertility, crop selection and protection measures. It would be even more beneficial if the crop rotation strategy in collaboration with the crop research organisation strategy could be used. The use of cultivation water reduction and high yield strategies could facilitate the process of improvement in agricultural output.

Furthermore, the health, education and sanitation infrastructure would be required. In this regard the role of commercial organisation can not be underestimated. Since the organisations are under obligation (under social and corporate responsibilities) to contribute to the community development areas, it could be expected that literacy, health, sanitation and employment programmes would be launched by these organisation in these areas in due course. It can be expected that the condition of these areas and the lives of the people therefore would be improved.

It is believed that a process of sustainable energy supply in the deserts is accompanied by the adoption of remedial measures, the study of which is made in the preceding section. A solution to these barriers is therefore imminent.

8.2. Remedial measures

Concerted efforts are required from the stakeholders to encourage the process of sustainable development in the deserts of Pakistan. The developmental process can be streamlined by the involvement of the local community, local government and non governmental organisations. Intensity of the social resistance to proposed development process could be diminished with the passage of time, in light of the positive changes such as electric power self-sufficiency, potable water availability and desert land reclamation that would be accrued in the desert environment.

Therefore it is opined that sustained efforts, monitoring, coordination and collaboration with civic agencies must be maintained until the resolution of such problems is achieved. There are certain recommendations for the successful implementation of the proposed pilot project, which are described in the following section.

8.3. Recommendations for successful implementation

The transition period would be associated with a balanced investment strategy. In this regard, the construction of a pilot project on a small scale is recommended, so as to workout the total project costs, which can then be scaled up for any number of desert community. The construction of micro and pilot projects could provide a good start at the preliminary stage. It would resolve the issues of large scale investment financing problems as well as monitoring of the worth of the processes used in the energy model.

It is believed that in the transition period, the role of academicians, researchers, planners, government agencies and donor agencies is vital for bringing awareness and interest among public and government.It would comprise on promoting the benefits of the desert resources development and to solicit the required size of funding and technical expertise in collaboration with the international, national, governmental and non governmental developmental organizations

Since the desert solar potential development process is dependent on the development of energy markets, the allocation of development funds and also the required infrastructure. In this regard, feed-in tariffs could be used for encouraging the solar industry to start projects in deserts. It is believed that considerable amount of work would therefore be required by the stakeholders and the future researchers for the utilisation of solar energy potential in and around the desert areas.

8.4. Future research work

The foundation of a self-contained and decentralised desert energy utilisation process, based on environmentally sustainable energy generation system is made. However, the detailed design of the structure would be required at later stages. In this regard it would be advisable to start with the development of prefeasibility and feasibility studies for the proposed system would also be required. A concise description of future work is given below.

It is believed that detailed designing of the desalination and solar power generation processes would be required, so as to workout the use of the most efficient solar cells type and technologies available in the market to maximise the scale of power generation.

It is also opined that further analysis on the emission analysis would be required to estimate the greenhouse gas emission reduction (mitigation) potential of the solar power generation process. This emission reduction analysis would include a description of the emission profile of the solar power generation process.

It is thought that the calculation of total cost of solar power generation and desalination plants would also be required, including the volume of the variable, fixed and miscellaneous costs in an effort to develop a potential cost-effective project proposal. Site investigation, resource assessment, an environmental assessment, a preliminary project design, a detailed cost estimate, a GHG baseline study and monitoring plan would be covered under the costs feasibility process.

It is believed that financial feasibility analysis would be required at the pre-implementation stage to analyse financial parameters, annual income, project costs and savings/income summary, financial viability, yearly cash flows and cumulative cash flows graphs. The study of financial parameters input items such as discount rate, debt ratio, and its calculated financial viability output items such as internal rate of return (IRR), simple payback and net present value (NPV) of the proposed solar plants would be required to facilitate the project's decision making process.

Finally, a risk and sensitivity analysis of solar power generation and desalination plants would also be required to estimate the sensitivity of important financial indicators in relation to key technical and financial parameters, showing the parameters which have the greatest impact on the financial indicators.

8.5. Conclusion

It is high time that the gravity of the energy scarcity situation in and around the deserts of Pakistan is realised. It is held that the solar energy powered development could change the energy scenario, and the fate of people living in desert and rural communities of Pakistan. It is believed that the problems of energy scarcity and supply line insecurity, which are due to the dependency on fossil fuels, could be diminished with the use of the solar powered energy utilisation process.

It is opined that in the long run, self reliance, energy sufficiency, environmental conservation and solar powered desert economy would be obtained in Pakistan. The construction of small, medium and larges scale power and potable water production processes could accommodate the demand of potable water, electrical power of the rising population.

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Appendix A –Pilot questions on power generation and desalination

I-FORMULATED PILOT QUESTIONS FOR A QUESTIONNAIRE SURVEY ON FOSSIL FUELLED AND SOLAR ELECTRICTY GENERATION

Q.1. Please could you indicate the volume of energy consumed on generation of 1kW electricity under existing power generation process?

Q.2. Please state how fossil fuelled thermal and hydel power generation are unsustainable, keeping in view the cost of environmental emissions.

Q.3. Is solar photovoltaic/solar thermal electricity generation method is better than the thermal and hydel power plants environmentally and economically? Please comment.

Q.4. Would you please to comment on the possibility that fossil fuelled thermal and hydel electricity generation would be replaced with solar electricity generation?

Q.5. It is widely believed that the thermal and hydel power generation systems are capable to supply electricity in desert and remote places? Could you offer some explanation to this notion?

Q.6. In solar rich country the method of solar thermal and photovoltaic electricity generation are better than thermal and hydel generation processes. Please comment.

Q.7. Looking into the upward trends in electricity prices of fossil fuelled power generation, and downward trends of solar electricity prices, what conclusion would you please to make?.

Q.8. Do you think that the electricity needs of commercial and industrial consumers can not be met coal/natural gas based thermal or hydel power generation system?

Q.9. It is believed that the transmission losses in the distribution of thermal power supply system are a liability, which can be removed by self-contained power generation systems. Would you please comment on this statement?

Q.10. What is the scope of the solar and oxy-fuel hybrid power plants for electricity generation systems? Please indicate.

Q.11. Please explain briefly how the thermal and hydel electricity generation can meet electricity needs in the long run?

Q.12. It is generally believed that the capital cost of a solar thermal or solar photovoltaic is recovered in a shorter span than the thermal or hydel power plants. Would you like to endorse it?

Q.13. Is the correct to say that the huge investment incurred on the thermal plants is a major barrier in construction of additional number of similar plants? Please comment.

Q.14. Please indicate the cost of emissions, which are produced during the electricity generation process and do you think that these costs can be reduced through solar photovoltaic or solar thermal power plants

Q.15. Please explain briefly which aspect of electricity generation would be better in solar power generation process?

II- PILOT QUESTIONS ON DESALINATION SYSTEMS.

Q.1. Which parameters of water desalination processes are considered in the water treatment process? How desalination process is a better water treatment option?

Q.2 Could you please describe the water treatment process used in the company for water treatment processes?

Q.3. Please elucidates how the specific water treatment process used in the company is better economically and environmentally?

Q.4. What problems are usually associated with the water treatment process? How a feasible desalination process can be ensured? Kindly explain.

Q.5. Would you please pinpoint any alternative water treatment process for getting freshwater without release of anthropogenic emissions?

Q.6. Would you please to comment on the statement that of all water treatment processes, solar desalination water treatment process is an inexpensive process?

Q.7. In your professional outlook, how solar desalination process can replace the fossil-fuelled powered water treatment process?

Q.8. In your scholarly opinion, which solar desalination process is more efficient, capable and low cost?

Q.9. Could you please to highlight the company database percentage of total freshwater is supplied to communities living in deserts and villages.

Q.10 What inputs are utilized in freshwater production, also what are its sources? Could you please to highlight the difficulties in getting the raw material inputs?

Q.11. In view of the expected water shortages in future, seawater can be utilized as an input for freshwater production**.** Please comment.

Q.12. Would you please to endorse the proposition that the share of solar desalination process should be increased?

Q.13. Could you please to inform about the electricity and emissions per tonne of freshwater are consumed.

III- QUESTIONNAIRE ON BRACKISH WATER DESALINATION

Name:	**Sex**
Designation	**Business**
Working experience	**Address**

SR. No	**Formulated Questions on Solar Water Desalination**	**Please Click the Relevant Box**				**Other Amount**
	Energy Consumption					
1	Which input water source is used for water treatment?	Brackish ☐	Sea water ☐	Waste water ☐	Drain water ☐	☐
2	How much energy is consumed per ton of freshwater production?	18 kW ☐	22 kW ☐	25 kW ☐	30 kW ☐	☐
3	How much power is consumed per ton of freshwater production?	3 kWh ☐	5 kWh ☐	6 kWh ☐	12 kWh ☐	☐
4	How much solar energy is consumed, in solar RO desalination water treatment process, per ton of freshwater production?	25 kWh ☐	50 kWh ☐	75 kWh ☐	100 kWh ☐	☐
5	How much waste/brine is produced per ton of freshwater production?	0.032 Kg ☐	0.05 Kg ☐	0.1 Kg ☐	0.25 Kg ☐	☐
	Environmental emissions					
6	How much CO_2 emissions are produced per kWh of electricity generation?	2.5 Kg ☐	5 Kg ☐	10 Kg ☐	15 Kg ☐	☐
7	How much NO_2 emissions are produced per ton of water production?	0 Kg ☐	5 Kg ☐	10 Kg ☐	15 Kg ☐	☐
8	How much SO_2 emissions are produced per ton of freshwater production?	0 Kg ☐	5 Kg ☐	10 Kg ☐	15 Kg ☐	☐
	Operational Costs					
9	What is THE cost of disposal of waste per ton of freshwater production?	$10 ☐	$11 ☐	$12 ☐	$15 ☐	☐
10	What is THE transmission cost per kWh of electricity from grid to the distribution centre?	$0.00 ☐	$1.00 ☐	$2.00 ☐	$4.00 ☐	☐

	Sustainability limitation					
11	Which freshwater treatment method is sustainable for water production?	Gas-fired ☐	Coal-fired ☐	Solar photovoltaic ☐	solar thermal ☐	☐
12	How much success chances are of solar photovoltaic water treatment method?	1% ☐	5% ☐	10% ☐	50% ☐	☐
13	How much confident can be said that solar photovoltaic is a clean source for water treatment method?	1% ☐	5% ☐	10% ☐	90% ☐	☐
14	How much confident can be said that solar photovoltaic driven desalination system is feasible method for deserts and barren places?	1% ☐	5% ☐	10% ☐	90% ☐	☐

IV-QUESTIONNAIRRE ON SOLAR POWER GENERATION

Name:	**Sex**
Designation	**Business**
Working experience	**Address**

	olar	10% ☐	25% ☐	50% ☐	100% ☐	75% ☐
	olar e	10% ☐	25% ☐	50% ☐	100% ☐	75% ☐

Sr.No	Formulated Questionnaire on Solar Power Generation	Please Click the Relevant Box				Other
	Energy Consumption					
1	Which solar method is more suitable for electricity generation?	Solar thermal ☐	Solar Photovoltaic ☐	Hybrid ☒	Oxy-fuelled ☐	☐
2	How much solar radiation is required for generation of 1kWh solar electricity?	5 kWh ☐	7 kWh ☐	8 kWh ☐	10 kWh ☐	☐
	Environmental Emission					
3	Which types of emissions are produced during thermal / photovoltaic electricity generation?	CO_2 ☐	NO_2 ☐	SO_2 ☐	SiO_2 ☐	None ☐
4	How much SiO_2 or CO_2 emissions are produced per kWh electricity production?	1 Kg ☐	1. 25 Kg ☐	1.5 Kg ☐	1.75 Kg ☐	☒
	Operational Costs					
5	What is the transmission cost of 1 kWh of electricity from grid to the distribution centre?	$0.00 ☐	$5.00 ☐	$10.00 ☐	$20.00 ☐	☐
6	What is the capital cost per kWh of solar photovoltaic panels/solar thermal power plant?	$200-300 ☒	$ 2000 ☐	$4000 ☐	$5000 ☐	☐
7	What is the cost of disposal of waste per kWh solar electricity?	£0.00 ☒	$1.00 ☐	$2.00 ☐	$4.00 ☐	☐
8	What is the percentage of transmission losses per kWh of electricity or more?	0% ☐	1% ☐	2% ☐	4% ☐	☐
9	What is the price of 1 Kwh of thermal/photovoltaic electricity generation?	$0.2.00 ☐	$0.3 ☐	$0.4 ☐	$0.5 ☐	☐
10	What is the cost of transmission losses per kWh of coal/natural gas powered electricity?	$1.00 ☐	$2.00 ☐	$3.00 ☐	$4.00 ☐	☐

III- Questionnaire Survey Samples

A .Water Treatment Companies in Pakistan
1(1). Khans Trading Karachi, Pakistan
Mob. Ph. 00923008999847, Email address.noman@khastrading.com

2 (2). Adaptive Technologies Private Limited,
Suite#03, 4th Floor, Dean. Arcade, Block-8, Clifton Karachi
Ph. 092215865896 and 5868044, Mob.Ph.00923452299908, Emails: faisal.i@adaptive-tec.com/info@adaptive-tec.com/farukh.m@adaptive-tec.com

3(3). A.PWT Water technology
Meehan Town Orangi Industrial Area, Karachi 74900
Tel.0321-2580255/03322-405252,Mob.0321-2580255/03322-405252,
Emails:operation@pwtonline.org/Zeeshan@pwtpakistan.com

4(4). Akhtar Solar Limited, Boland Markus, 33-Blue Area
Islamabad – 44000, Pakistan, Ph. No.: +92-51-2829803
Mob. Ph: +92-321-8552534, Email: sharjeel@akhter.com/info@akhtersolar.com

5 (R. J. Allam, PLC et al.). Alt-Energy Tech Inc. Pakistan (PVT) Ltd.
Maqam-e-Farhat, R-85 Block 13-B-1, Gulshan-e-Iqbal, Karachi 75300, Pakistan
Ph. No.: 0333-319-1763/ 281 3333 9889/286 3726, Email: bsyed@worldnet.att.net, aa@atrc.net.pk

6(kWh). Clean Power (PV) Ltd.
216, Street 74, 1-8/3, Islamabad, Mobile: +92 333 5131574, Ph. No.: +92 51 4102271 3
Email: ammad@cleanpower.com.pk. Web: www.cleanpower.com.pk

7(R. J. Allam, PLC et al.). Crest International Trading Company
136/B, Choudhri Rehmat Ali Road, SMCHS, 2nd floor, Karachi 74400, Pakistan
Ph. No.: +92 21 4549650-2 and 4313940-1, Email: citcopak@yahoo.com

8(R. J. Allam, PLC et al.). National Engineering Corporation
202 Sea Breeze Plazas, Main Shah rah-e-Faisal, Karachi – Pakistan
Ph. No. +92-21-2788336/+92-21-2788337, /+92-21-2782368, /+92-21-2785558
Email: nec@cyber.net.pk

9(R. J. Allam, PLC et al.). Sanderson: Solution to Energy Saving
551-A-I, Johor Town, Lahore, Pakistan, Mobile: 0300-8491613, Ph. No.: +92 42 5177898
Email: ceo@synercon.com.pk Web: http://www.synercon.com.pk/

10 (10). Trillium Pakistan (Pvt) Ltd.
10th floor, AWT plaza Rawalpindi, 5-The Mall, Pakistan, Tel.00923335975435, /0092-51-5524181, 5524182, 5567614, 5562107 Ext .121,Email:.n.afzal@trillium-

pakitsan.com/trillium.pak@dsl.net.pk/mohsin@infosecurity.com.pk/n.afzal@trilliumpakist an.com

B- Mazda Institute of Science and Technology, Abu Dhabi, UAE
11(1) Mr. Hassan Faith, Professor, UMIST, UAE, Researcher on solar desalination and power generation, Email:hfath@masdar.ac.ae

12 (2). Mr.Jaswal, postgraduate student, Mazda Institute of Science & Technology, Abu Dhabi, UAE

C. Electricity Generation Companies in Pakistan
131) PEPCO, Lahore
725-WAPDA House, Lahore, Pakistan, Email:admms172@yahoo.com,Tel:4299202529, Mob.Ph:00923004643976

14(2). Habib Rafiq Private Limited
6-K, Block-H, Gulberg-II, Lahore,
Tel, 924235711411/009235711716/00924235712944, Email:hr@habibrafiq.com Kot Addu Power Plant,

15(3) Kot Addu Power Complexes, Kot Addu
District Muzaffargarh (P.C. 34060), Tel. +92 (R. J. Allam, PLC et al.)66 2301 041, Email: info@kapco.com.pk
/ rukhsana.tehreen@kapco.com.pk

16 (4). Jamshoro Thermal Power Plant,
Mohra Jabal Dadu Road Jamshoro Sindh Pakistan.
Email: akram_ce@yahoo.com/ mail@jpcl.com.pk/ceo@jpcl.com.pk and ceojpcl@wapda.gov.

17 (R. J. Allam, PLC et al.) Descon Engineering Ltd. Karachi
5. 2x100 MW Combined Cycle Power Plant Kot Addu Units 9 and 10, 9th Floor Business Avenue, 26-A Block-6, P.E.C.H.S, Main Shah rah-e-Faisal, Karachi,
Phone: (92 21) 34544481~4, Email:shakeel.rehman@descon.com/desconkarachi@descon.com.pk

18(kWh) Hub River Thermal Power Plant,
Descon Engineering Ltd. Lahore, 18 km Ferozepur Road, Lahore, 53000, Pakistan, Tel: (92 42) 35990034, 35805134, Email: descon@descon.com.pk

19(kWh) HUBCO, Karachi
Islamic Chamber of Commerce Building, ST-2/A, Block-9, Clifton, P.O. Box No. 13841, Karachi - 75600,
Tel: 92 21 35874677-79/92 21 35874677-80, Mob. Ph:00923028270499/
Email:info@hubpower.com/karachimo@hotmail.com,Tel:00922135874677/vakil@power.comhubpower.com

20 (R. J. Allam, PLC et al.). Siemens Pakistan, Karachi
B-72 Estate Avenue, S.I.T.E, Karachi 75700.
Tel: 0092(R. J. Allam, PLC et al.)2132574910-1932592000, email:
zia.zuberi@siemens.com /
Sohail.mehmood@siemens.com,
Tel.00922132567573/Mobile 00923222224008/.00922132592024. Mr. Sohail assured on 16-07-2010, to send the replies on 19-07-2010.

21 (R. J. Allam, PLC et al.). Orient Energy Systems
Plot No.16, Sector 24, Korangi Industrial Area, Karachi
(Head Office), Phone: + 92 21 35072091-94, Fax: + 92-21-35077105/+ 92 21 5077101-04. Email: info@orient-power.com./kashif.siddiqui@orient-power.com.faisal.majid@orient-power.com. Tel mob.00923452529402/00923219256982

D. Solar Power Generation in Pakistan
22(1). Pak Solar Power
17-Civic Centre 1st Floor, New Garden Town, and Lahore
Tel: 042 7070770, 5836982, Email:
solarenergy@hotmail.co.uk/inquiry@paksolarpower.net /sales@paksolarpower.net /info@paksolarpower.net

23 (2). Adaptive Technologies (Pvt) Ltd.
Suite #3, 4th floor Dean Arcade, Block – 8, Clifton, 75600 Karachi, Ph. No.: +92 21 586 5896, 586 8044, Mob.00923452299908, Email: adaptec@multi.net.pk / faisal.i@adaptive-tec.com

24 (3). Akhtar Solar Limited
Factory plot # 11, 12 Industrial Area Hattar, HariPur District.
Tel: 0995-617205/+92(R. J. Allam, PLC et al.) 51-5111221, Email: info@akhtersolar.com, Mob.03218555494

25(4). Alt-Energy Tech Inc. Pakistan (PVT) Ltd
Phone: +9221 3498 7017 Email: bsyed@worldnet.att.net, aa@atrc.net.pk

26. Hi-Tech Alternative Systems Pvt. Ltd
Email: hitech.solar.wind@gmail.com/ hitech@cyber.net.pk, Phone: +92 21 3562 1864, Mob.00923008228268.

27(kWh). Saphire Renewable Solutions Pvt. Ltd
Email:adeel.zahid@srs.com.pk/info@srs.com.pk,
Tel.00924235756497Mob.00923034444553; Email: Tel.009242111000100

28BMM Technologies (Pvt (ltd)
33-Blue Area, Islamabad, and Tel: 0092-51-2829803-6/ob. 00923005758442, Email: info@bmmtechnologies.com/ engr.irfanrasul@gmail.com.

29(R. J. Allam, PLC et al.). Solar Communication Power Systems (Fusion Group International), Phone: +92-21-8095857 +92-332-2598275, E-mail: info@fusionsgroup, Tel: 00923322598275.

30Sun Star Solar (Solar Home Systems)

MZ 41, Central Plaza, Barket Market, Garden town, Lahore Pakistan, Phone: +92 42 35940967-35022788, 0323-4244441, Email: info@sunstarsolar.biz

31(10). Emerging Energy Systems.
12-A, Street 29, F-7/1, Islamabad, Tel: +92 51 2652511/12 email: info@ees-energy.com
Karachi Office: G-3, 140-Q, PECHS, Block 2, Karachi, Tel: +92 21 3438-2952/53, Alam Plaza Sec/F1 Kotli Road, Mirpur Azad Kashmir, Phone:-05827-437296-7. Mobile: - 0313-5656820, Email:ayyazbazmi@gmail/yahoo.com

32 (11). Solar Small Home Systems.
Email: - info@sbsae.com

33 .Solar Systems Pakistan Private Limited
UG 59, Eden Tower, Main Boulevard, Gulberg,
Lahore, Mobile Phone: 0321 9604344 (09:00am-17:00pm), Phone: 042 35753450
Email:contact@solarsystem.pk

Appendix B- Publications

Journal papers

1. Sadiq Ali Shah, Yang Zhang “Prospects of Coastal Solarisation for Freshwater and Electricity Production” ISESCO Journal of Science and Technology Vision”, Vol.06, Issue November 10, 2010, Published.

2. Sadiq Ali Shah, Rodger Edwards, Yang Zhang, “Hybrid Energy Based and CO_2 Sequestration Capable Desert Potential Development, National University of engineering and technology (NUST) Journal of Engineering Sciences, Volume-III, August 2011.Published,http://njes.nust.edu.pk/Images/Contents-3.pdf

3. Sadiq Ali Shah, Rodger Edward Edwards Yang Zhang, The impact of Desert Solar Power Utilisation on Sustainable Development, Applied Solar Energy, Vol-III, 2011, published.

4. Sadiq Ali Shah, Rodger Edward Edwards, “Sustainable Energy Generation Processes in the Deserts of Pakistan, International Journal of Sustainable Energy, 2011.Published

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Prospects of Coastal Solarisation for Freshwater and Electricity Production

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Abstract

Freshwater and electricity are basic amenities for human survival, without which sustainable environment can not be attained, nor the standard of life is raised. Coastal areas in solar-rich countries can be utilized for the production of freshwater and electricity and a case study of Pakistan is made to analyse its positive impact. Pakistan is a solar-rich country with long coastal areas. However, these resources could not have been utilized for the production of freshwater and electricity. The paper analyses a strategy for the development of indigenous renewable energy sources. The solar powered electricity and desalinated water are practicable means to produce freshwater and electricity with no environmental cost. The development of self-contained solar powered and desalination and electricity systems in coastal areas can resolve the issues of Saline water and unavailability of electricity in coastal areas. Considerable amount of solar powered electricity and freshwater production is attainable in coastal areas of Pakistan.

Keywords: *Solar energy, Coastal land utilization, Freshwater production, Electricity generation.*

1. Introduction

Pakistan, despite being a solar-rich country, faces the acute challenges of energy deficit. The country is running out of conventional energy sources very rapidly [1]. The current energy scenario reveals small share of renewable energy sources and utilization of alternative energy utilization approaches. Therefore it is crucial to devise a diverse energy strategy based on diminishing dependence on vulnerable energy supply channels and explores sustainable energy resources such as renewables [2]. Moreover, major electricity generation sources are conventional such as oil, gas, hydel and nuclear, and the share of renewable energy is less than 1% despite the fact that solar potential as compared to conventional energy resource. Pakistan spend 3 billion US dollars every year to import oil with annual growth rate of 1% [3]. Electricity generation by fuel source is illustrated in *Figure 1*.

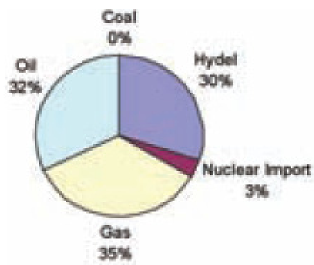

Figure 1. Electricity generation by source in the year 2007-08 [4].

The utilization of indigenous solar energy sources can lead to the path of sustainable energy development processes in remote areas. Installation of solar powered plants in coastal areas is a viable option for electricity generation at potentially low average cost and emissions [5]. The coastal belt of Pakistan extends to 1046 sq. km. Of this 930 km is from the Karachi to Gwader region in the province of Baluchistan. The coastal areas of Pakistan has a population of about 10 million people [6]. Most of the areas in Pakistan receive intense solar radiation on largely-uninhabited land with little or no agricultural potential and, consequently, a low opportunity cost of utilization [5]. Solar energy can be utilized to meet the electricity and freshwater needs of coastal and adjacent village communities. The energy scarcity and costs can also be brought down by utilization of solar energy by local production of solar cells and by economies of scale. Concerted efforts are also made by the government for PV modules production with an expected capacity of 3MW/year are [7].

Moreover, it is well established that PV is a cost-effective technology, as its maintenance costs are negligible compared with fuels systems, and enjoys a long life, usually 20-30 years, which make them more reliable and attractive than fossil fuel systems [8, 9]. An important aspect of solar PV generation is the self-contained nature, which facilitates the process of energy generation in remote places, without incurring the expenditures on transmission systems, and eliminates transmission losses. Not much basic infrastructure is required for the development of these self-contained energy systems.

2. Methodologies

Solar photovoltaic cells powered electricity and desalination methods are used for the production of freshwater and electricity. Seawater can be pumped from sea to desalination plants at these coastal sites. Solar powered reverse osmosis process can produce one ton of freshwater from the average amount of solar energy i.e. 5 kWh falling on $1m^2$ area [10].By this way enough electricity for desalination process can be generated, as the land spaces are available around the costs at small or no cost. The large land spaces around the coastal areas can be utilized for installation of the solar panels. It can resolve the issues of land cost, which is considered a major cost item besides the cost of solar cells. The power produced from solar photovoltaic can be utilized for electricity generation and conversion of seawater to freshwater. Besides solar panels coal powered oxy-fuel combustion power plants can be installed to reduce solar panel costs.A substantial amount of fossil fuels can be saved and the resulting environmental emissions can be avoided if solar photovoltaic power generation is utilized in the industry and for power generation.

An important aspect of coastal solarisation process is its self-contained nature of solar energy generation system, which makes these systems free from transmission losses, theft and transmission line investment. The use of photovoltaic solar panels, can play a vital role by decentralizing electricity generation as well as eliminating the needs for transmission and distribution [1]. Large terrestrial photovoltaic power stations, about 100 MW capacity operate as stand-alone in the United States [11]. Solar PV stand alone micro projects along coasts could be planned instead of initiating any mega/macro PV project on commercial scale in a bid to attain self sufficiency and supply of basic amenities to communities living in vicinity of the costal areas. [4].

Another reason to propose solar option for the production of freshwater and electricity in coastal areas is the one time capital cost on installation of solar panels and zero fuel cost of solar electricity. According to figures, Ghazi Barotha Dam cost Rs. 118 million per MW (US% 2.2 billion for 1400 MWI in comparison to solar thermal power system costing Rs. 70 million per MW due to saving in construction costs [12]. PV cells are usually sold in Pakistan at the rate of $ 7 per watt along with storage batteries, that is $70 million for a 10 MW plant, converters, and installation charges [13]. Concerted efforts have been made for increase in the efficiency of solar cell. Pakistan Council for Renewable Energy Technologies (PCRET) have achieved 13% efficiencies on 4 in. round plainer solar cell with single layer antireflection coating [14].

3. Viability of solar electricity

Pakistan is a solar-rich country, and is bestowed with high solar insolation and long sunny days most of the year. Pakistan is located in the sunny belt to take advantage of solar energy technologies [1, 9, 15, 16]. On average Pakistan receives 7-8 hours sunshine and solar radiation 5-8 kWh/m2/day over more than 95% of its area with 85% persistence factor [1, 4, 17]. Since photovoltaic electricity generation capacity is measured in square meters or kilometres, therefore it is assumed that half the coastal land, i.e. 523 square kilometres is available for its utilization. If 10% solar electricity utilization targets are set every year in the costal areas, especially in costal belt, it can produce huge amount of electricity. The amount of electricity production by 10% solar utilization in Pakistan is in ***Figure 2***.

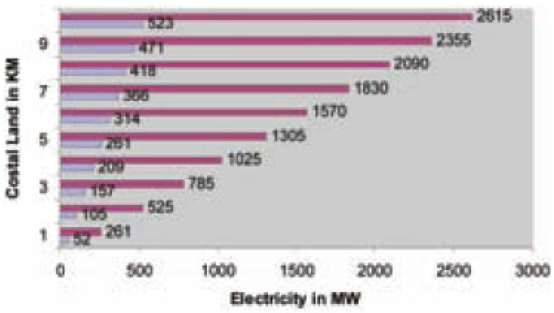

Figure 2. Expected electricity generation capacity over costal land.

The annual mean values of insolation lie between 16.0-21.0 MJ/m²/day with 19.0 MJ/m²/day over most parts of the country [9, 18]. The greatest value of 15.5 MJ m²/d occurs along the coastline of Baluchistan and the central part of Sind in the month of January, revealed in the January map of typical winter distribution of daily global insolation [19]. The south-western province of Baluchistan is particularly rich in solar energy [20] with an average daily global insolation of 19-20 MJ/m² a day (1.93-2.03 MWh per m² in a year) and annual mean sunshine duration of 8-8.5 hours. Such conditions are ideal for photovoltaic (PV) and other solar energy applications. The Energy Information Administration describes the daily solar energy potential for Pakistan as 5.3 KWh per m² (1.93 MWh per m² annually) [20].

Solar electricity costs are also optimized with the passage of time. The factory prices for single and polycrystalline silicon modules have decreased to US$2.90, and amorphous silicon modules are reportedly being sold at prices of $2.00-3.00 per watt, with the result that solar powered electricity costs in Pakistan are US $0.20 [7]. Moreover, the levelised cost of producing electricity from a 10 MW solar PV plant comes to 27.2 cents/kWh [13]. Intensive efforts are made for the local production of solar cells on economies of scale. National Institute of Silicon Technology, Pakistan has a capacity of assembling and manufacturing 3 million solar cells [21]. National Engineering and Science Commission (NESCOM) and Solar Energy Centre (SEC) are engaged on production of photovoltaic panels and designing of solar thermal appliances, respectively. Almost all the villages in and around the coastal belt can be electrified and freshwater can be made available through coastal solarisation development process.

The self-contained solar power generation systems are economical choice for Pakistan in terms of optimization of line losses and transmission line expenses. The current losses in the power generation system in Pakistan are 24% of the total power generated [8, 22]. These include losses incurred during transmission and distribution as well as due to theft. Pakistan suffers from a massive electricity shortage. The high electricity demand can be also being stabilized due to increase electricity generation capacity of coastal solarisation process. Solar photovoltaic is also a feasible option for Pakistan as these systems are free of fuel costs, maintenance costs, and are free from environmental emissions. Solar energy is a renewable form of energy that does not have any direct environmental impacts [15].

4. Prospects of freshwater production

Demand of freshwater is on rise in Pakistan due to high increase in population. Pakistan is one of the countries classified by United Nations Environment Program (UNEP) through its OCA/PAC regional seas program, as being particularly vulnerable to the effects of sea level rise [15]. The residents of coastal areas use saline water jeopardizing their health due to unavailability of freshwater in these areas. The development in the coastal areas is not possible without exploring new sources of fresh water such as desalination of seawater [23]. Moreover, freshwater supply levels in Baluchistan are not up to the mark. Most of the coastal areas are dry, and have low annual rainfall ratio. The goal of supplying freshwater to coastal communities and adjacent rural areas could not have been attained so far due to resource immobilization.

Solar desalination is an accepted method for converting brackish or saline water for drinking purposes. The option of Solar Photovoltaic (SPV) powered water pumps is also possible, because of the availability of average daily solar radiation greater than 3.5 kW/m² on a horizontal surface [24]. Pakistan Council of Scientific and Industrial Research (PCSIR) have already installed solar desalination plants at different locations. Freshwater production at the coastal and its adjacent areas is the most important factor for the sustainable development of the people living in and around these areas, to raise their standard of life or to increase their per capita energy consumption. The use of seawater on large scale may also lessen the vulnerability of seawater rise, which is rising gradually due to global warming process.

There is huge potential of freshwater at these coastal areas due to easy availability of input raw material of seawater and solar electricity. Seawater can be made available to the potential deserts by pumping it from sea, which can be desalinated to get freshwater. Therefore the amount of freshwater to be produced in the coasts if entire costal area of is utilized at 10% expansion each year is depicted in ***Figure 3***.

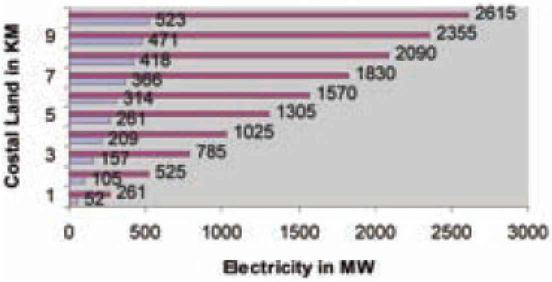

Figure 3. *Capacity of freshwater production over 10% percentage coastal land utilization.*

Desalination of seawater is a feasible method for the sustainable development and management of freshwater resources in coastal and adjacent rural areas of Pakistan. Karachi nuclear power plant (KANUPP) is already operating a Sea Water Reverse Osmosis (SWRO) plant to meet its operating requirements [23]. The amount of freshwater produced every 10% costal land, as projected in figure 3 is considerable and leads to the development of costal areas and adjacent rural areas.

5. Results and discussion

The costal areas in Pakistan are lagging behind the developmental process due to lack of development initiatives. The arid and semi-arid areas of Baluchistan and Sindh have meagre surface flows and the people have to depend on underground porous and permeable rock reservoir [25]. Coastal (arid and semi arid) are particularly suitable for solar/wind combined system because of their high proportion of cloudless days [18]. The Baluchistan coastline extends over 750 kms from Hub, to the Gawadar bay. Karachi, Ormara, Jawani and Pasni are the potential coastal sites. The geographical view of the coastal sites is depicted in ***Figure 4***.

Despite the exploration programme for supply of freshwater to these costal areas there is no substantial progress in power and water sector. Most of the groundwater is highly saline, and rainfall is the only source

Figure 4. *Map of Pakistan showing coastal areas of Jawani, Pasni, Karachi and Gawadar [26].*

of freshwater source. The gravity of the situation can be realized from the fact that rainfall is the only source of freshwater source in deserts, which occurs mostly during monsoon from July to September [27]. The standard of life is poor due to lack of water storage facilities. The groundwater is mostly saline and unfit for human and livestock drinking [28]. Since on average 5 kWh power can be produced by 1 m^2 solar panel per day in most of the areas, it can be presumed that 1 kilometre square coastal land can produce 5 MW electricity and 833 tonnes of freshwater per kilometre square per day. Therefore million of tonnes of freshwater and mega watts electricity can be generated if the whole coastal belt is utilized. The availability of freshwater and electricity can change the fate of these coastal communities thereby increasing their standard of living.

6. Suggestions and recommendations

- Increase in the utilization of solar energy for the production of freshwater and electricity in the coasts.

- Survey of all the coastal areas for development coastal plans in respective areas.

- Establishment of coastal development authorities to cater the construction of solar energy power and desalination plants in these areas on national, provincial and regional levels the coastal development projects.

- Feasibility studies of all costal areas for the development of coastal development projects.

- Allocation of funds in the development budgets for the supply of solar powered freshwater and electricity in coastal areas.

- Carrying out environmental assessment for estimation of environmental costs saving due to solar powered processes.

- Indigenous production of high efficiency solar cells and to benefit from the economies of scale.

- Intensive monitoring of coastal development plans at implementation stage to make them successful.

- Launching pilot coastal development projects.

- Further research on coastal solarisation for better outputs and less costs.

Conclusions

Coastal Development Authority can be established to initiate the process of electricity generation and freshwater production over all the coastal areas. The developed methodology can be implemented in the coastal areas of Karachi, Gawadar, Pasni, and Jawani for the supply of electricity and freshwater to the communities living in and around these coasts. The proposed costal development process may change the fate of the costal communities and would provide them the basic necessities of life. The development process could enhance the national electricity and freshwater capacity and contribute to diminishing the dependence on fossil-fuelled economies. A fascinating aspect of desert development model is the development of indigenous renewable energy sources for the supply of freshwater and electricity in deserts. The ongoing process can promote sustainable activities in the coasts, creation of commercial activities and is accompanied with environmental and economical changes.

Acknowledgement

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Contents

Hybrid Energy Based and CO_2 Sequestration Capable Desert Potential Development

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Abstract
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Key Words: Solar energy, CO_2 sequestration, desert development

Introduction

Energy scarcity, environmental pollution and high fuel prices are all problems in terms of energy production in Pakistan. Due to high population rate, there is continuous increase in power demand. [2, 3] However, due to the gap in supply and demand, a substantial decrease in per capita electricity consumption (350 kWh) is observed.

[4] Pakistan has been facing acute challenges of energy deficit for quite a long time. The country's oil and gas reserves are also depleting at a rapid rate, resulting in an increase in the import of crude oil. [1] Pakistan's total primary energy supply during 2008–09 was 62.88 MTOE (million tonnes of oil equivalent). The nature of primary energy supply sources of Pakistan are highlighted in Fig.

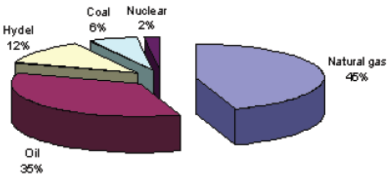

Fig.1: Primary energy supplies in Pakistan in 2009-10 [5]

The figure reveals a large share of oil and gas, followed by hydro and coal fuels. Due to dependence on oil and gas powered carbon economy, the country is facing serious threats of environmental pollution. [6, 7] However, the share of renewable energy sources is negligible. The sensitivity of the situation can be realised from fact that a large share of fossil fuels is used in the power generation industry, as highlighted in Fig. 2:

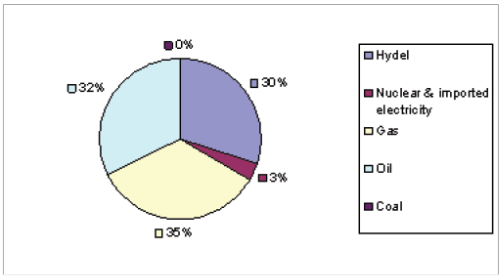

Fig.2: Power generation by energy source in 2008-09 [8]

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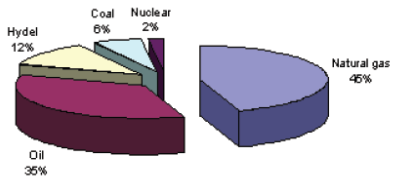

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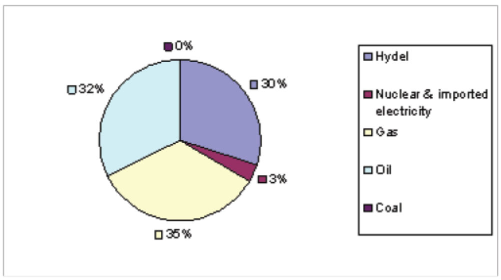

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[9] Therefore, it is crucial to explore renewable energy generation processes to diminish dependence on imported oil and to increase the use of indigenous sources such as solar energy and coal in major sectors of the economy. Hybrid systems such as solar energy and natural gas are used globally to enhance existing energy capacities. [10, 17] Solar energy and natural gas technologies are proposed for DESERTEC project in MENA (North Africa and Middle East) region.

In light of the potential of solar energy and coal in Pakistan, hybrid-energy-powered and CO_2-sequestration-capable desert potential utilisation model is developedillustrated in Fig.3. The primary inputs of the proposed model are solar energy, air and coal. [23] An important aspect of this energy model is the self-contained nature of power generation processes in a sustainable manner. In this model, CO_2 produced by coal-fired oxy-fuel power generation can be sequestrated.

[8,7] The desert development model can be utilized for the supply of electricity to 25,000 villages/settlements besides deserts, where electricity supplies from a national grid and other sources is not possible or is uneconomical.[3] The proposed model project can be implemented in collaboration with Alternative Energy Development Board (AEDB), Pakistan Council of Renewable Energy Technologies (PCRET), which are actively engaged in the development of renewable and alternative energy development processes.

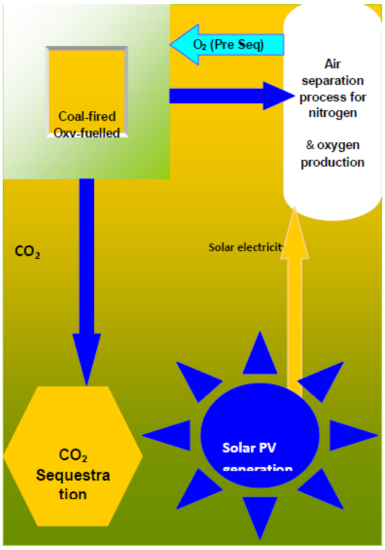

Fig.3: Illustration of the desert potential development model

Methodologies

There are four levels of processes in the desert potential development model. At the first level, power generation is accomplished by solar photovoltaic and coal-fired oxy-fuel combustion process. Coal-fired power plant could provide power supply round-the-clock.

At the second stage, pure oxygen is produced from atmospheric air by the utilisation of air separation process. In the third step, coal-fired power generation takes place. Oxy-fuel combustion process produces 75% less flue gases than air-fuelled combustion. The content of oxygen in the oxy-fuel combustion process is 95%; the resulting emissions are carbon dioxide and water. Carbon dioxide separated by oxy-fuel combustion process can then be sequestrated in the final stage.

Viability of Solar Potential

Pakistan is a solar-rich country, and is blessed with abundant solar radiation due to its ideal location in asunny belt. As such, the country can benefit from solar energy. [13] It has been estimated that over the total geographical area, that is, 796, 095 km2 the available solar energy potential is 5.23 PJ/m2/year. [4, 8, 12, 15] Pakistan receives an average solar radiation of 5–8 kWh/m2/day with an 85% persistence factor on more than 95% of its area. [9] The annual incident solar radiation in the country is in the range of 1900–2200 kWh/m2. [13, 15] The annual mean values of insolation are 19.0 MJ/m2/day over most parts of the country. [7] The mean values of insolation are from 12-13 MJ/m2/day in December/January to 25-26 MJ/m2/ day in June. [16].

[19, 4] Therefore, solar energy could be utilised feasibly for clean power generation process. [13, 23] Furthermore, it is well established that PV is a cost-effective technology as its maintenance costs are small compared with fossil fuel systems. Solar panel modules and electricity generation costs have also decreased with the passage of time. The single and polycrystalline silicon modules manufactured in Pakistan are sold at the prices of $2.90 and $3.25 and amorphous silicon modules at the prices of $2.00-3.00 per watt. [3] A comparative analysis of a 10 MW solar photovoltaic and fossil fuel power plants led to

the findings that though PV systems have high capital costs yet these plants have zero fuel costs, longer life and incur much less maintenance costs than fossil fuel plants of the same capacity.

[21] The Pakistan Council for Renewable Energy Technologies (PCRET) has developed solar cell production capacities to pilot scale, and their planned target for 2011-15 and 2016-2020 are 5 and 20 MW. [37] Akhtar Solar, a subsidiary of Silicon CPV plc, is also engaged in the assembling and manufacturing of solar panels since 2005, and has succeeded in the manufacturing of panels for domestic users. [24] Therefore, the potential utilisation, as stipulated in the model, in the deserts of Pakistan could be used to supplement the existing power generation sources. The electricity produced in these deserts could be transmitted to the nearest national grids to rebalance the gap between demand and supply in Pakistan.

Feasibility of Pulverised Coalfierd Power Generation

Pakistan is a coal-rich country as well. Coal is available in bulk at Thar, desert. Thar Desert coal reserves in Pakistan could be utilised for power generation for a very long time. [25, 36] The total electricity generation potential of the Thar coal is 5000 MW, which could last for 800 years, based on an estimated consumption of 536 million tonnes of coal. Oxy-fuel combustion process could be configured with coal-fired power plant for carbon separation and sequestration. However, the existing share of coal in power generation in Pakistan is very small, as shown in Fig. 4.

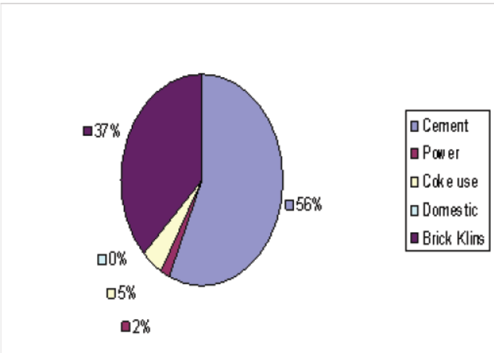

Fig.4:Share of coal fuel in major industries (2007-08) [8]

[36] It is important to note that coal is also an inexpensive fuel. Pakistan can produce electricity from coal at a low price. [38] In a study carried out by PB Power, it is found that electricity can be generated from coal–fired power plant at the cost of $250 to 320/MWh. Therefore, use of coal in power generation could bring down electricity generation costs. The amounts of electric power that could be generated from each tonne of the coal, based on 2 kWh electric power/kg coal, are estimated, in Fig. 5.

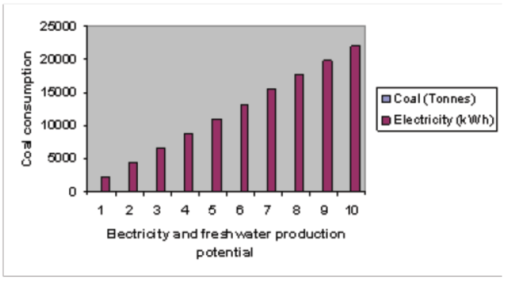

Fig.5: Estimated amounts of coal-fuelled electric power

Oxyfuel Combustion

Since, coal-fired power plants contain flue gases and CO_2 as a dilute gas, which makes the sequestration process difficult and costly, therefore oxy-fuel combustion process is integrated with coal-fired power generation in the proposed model. [35] In this process, the mass concentration of flue gases in oxy-fuel combustion process are increased to 48 (molecular weight of CO_2) in comparison to 28 (molecular weight of N_2) (28). [35] However, the amount of electricity generated by a power plant using anoxy-fuel combustion is less than conventional coal powered plants, because it drives oxidiser and compressor that result an average 9% reduction in plant efficiency.

Air Sepration Process

Oxygen can be attained from atmospheric air by hybrid membrane and cryogenic distillation system. [33] In this process O2/N_2 polymeric membrane, under induced pressure difference, could be utilised to separate oxygen from air, which is then processed in a cryogenic stage to get it further pure. Coal-fired power plant and air separation unit can be integrated to attain the objectives of power generation and carbon sequestration. [34] Both plants require pure oxygen mixed with recycled flue gases to maintain adiabatic flame temperature.

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The energy mass balance for air separation process can be estimated on the basis of the composition of oxygen in atmospheric air. In the air separation process, electricity consumption in oxidiser is a main cost item for generation of oxygen. Since for every one mole of carbon, two moles of oxygen are required to produce carbon dioxide (combustion equation), therefore for every one tonne of coal, two tonnes of oxygen would be required, which would produce two moles of carbon dioxide. [34] Therefore, for each tonne of oxygen production 448 kWh energy would be required.

Potential Desert Sites in Pakistan

Since large land spaces are required for the installation of solar panels for phototvoltaic power generation, therefore low opportunity cost deserts' land spaces are proposed as suitable sites.[28] Approximately, 70 million hectares of Pakistan have arid or semi-arid climate and out of 41 Mha of arid areas, 11 Mha falls under the category of main deserts. 15] The basic amenities, like electricity is scant in these deserts. These deserts are rich in high radiation solar energy and coal reserves. [10,11] The intense solar radiation received by the deserts of Pakistan, together with lignite coal reserves at Thar desert means that there is low opportunity cost for utilization.

A potential assessment of power generation and energy equivalent at the desert of Thar, Cholistan, Thal and Chaghi Kharan. The climatic data the cities near to these deserts is obtained, which is processed in RetScreen International software (RetScreen, 2011) to get the amount of electric power generation and the associated costs. The break up of the amounts of electric power to be exported, the energy equivalent and capital costs are provided in Table 1.

Table 1. Estimated (solar PV) power, energy equivalent and plant costs

Percentage solar (PV) utilisation	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	Total
Cholistan											
Solar (PV) electricity exported to the grid/ day (GWh)	193.5	387	580.5	774	967.5	1161	1355	1548	1742	1935	10642.5
Energy equivalent (P J)	0.69	1.39	2.08	2.78	3.48	4.17	4.87	5.57	6.27	6.96	38.26
Capital Cost in Million ($)	223	446	669	892	1115	1338	1561	1784	2007	2230	12265
Thar											
Solar (PV) electricity exported to the grid/ day (GWh)	162.7	325.7	488.7	651.7	814.7	977.7	1141	1304	1467	1630	8962
Energy equivalent (P J)	1.58	1.17	1.75	2.34	2.93	3.51	4.1	4.69	4.28	5.86	32.21
Capital Cost in Million ($)	188.7	377.4	566.1	754.8	943.5	1132	1321	1510	1698	1887	10378.5
Thal											
Solar (PV) electricity exported to the grid/ day (GWh)	170.1	340.3	510.5	680.7	850.9	1021	1191	1362	1532	1702	9360
Energy equivalent (P J)	0.61	1.22	1.83	2.45	3.06	3.67	4.28	4.9	5.51	6.12	33.65
Capital Cost in Million ($)	197.3	394.7	592	789.4	986.7	1184	1381	1579	1776	1973	10853.7
Chaghi Kharan											
Solar (PV) electricity exported to the grid/ day (GWh)	133.1	266.3	399.5	532.7	665.9	799.1	932.3	1066	1199	1332	7325
Energy equivalent (P J)	0.47	0.95	1.43	1.91	2.39	2.87	3.35	3.83	4.31	4.79	26.3
Capital Cost in Million ($)	154.4	308.9	463.3	617.8	772.2	926.6	1081	1236	1390	1544	8494.2

Carbon Sequestration

Carbon dioxide emissions released from the coal-fired power plant can be sequestrated by either deep ocean storage or underground geological sequestration. [31, 32] Since underground carbon sequestration is at early stage of development, therefore, it is less feasible than underground geological sequestration. [31] Moreover, good and limited geological sequestration storage potential exists in most of the areas of Pakistan, which is highlighted in a survey map of British Geological Society, 2007. In this method, carbon dioxide could be stored in deep underground layers such as natural gas and oil fields. [32] By this method, carbon dioxide could be stored securely similar to natural gas storage in geological formations. The problems of CO_2 leakages and salinity, can, however, be looked after properly. [32] Carbon separation and carbon dioxide sequestration process would also provide means to stabilise carbon dioxide concentration in the desert environment in the long run.

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Conclusion

The ongoing potential analysis of deserts reveals that the proposed methodologies can sustainably resolve the problems of electric power shortage, environmental emissions and high power costs in Pakistan. The proposed desert potential development model may change the fate of the power industry. The ongoing process can also promote commercialization,industrialisation activities in the deserts andthe creation of employment opportunities. It would bring ultimately deep social, environmental and economical changes.

Nevertheless, considerable challenges exist in the realization of this objective, such as resources immobilization, lack of initiatives, lack of awareness, and lack of institutional infrastructure, for which concerted efforts are required from concerned quarters, so that short, medium and long term projects can be launched in the deserts.

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Acronyms

AEDB: Alternative Energy Development Board
Fig: Figure
kWh: Kilo watt hours
MENA: Middle East North Africa
MJ; Mega Joules
MTOE: Million Tonnes of Oil Equivalent
MW: Mega watts (106)
PICRET: Pakistan Council of Renewable Energy Technologies
PV: Photovoltaic
PW: Peta watts (1012)
CO_2 :Carbon di Oxide
O_2 : Oxygen

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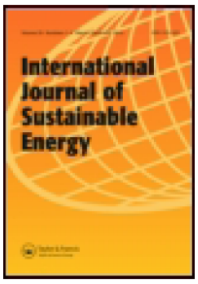

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Sustainable energy generation processes in the deserts of solar-rich countries

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Sustainable energy generation processes in the deserts of solar-rich countries

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A sustainable energy generation system in solar-rich countries can establish the process of desert community development in these areas. To test the validity of this hypothesis, potential assessment of deserts' solar power is carried out. The results reveal that considerable amounts of electric power and potable water can be produced locally at these deserts sites. In this paper, the basic needs of a sizeable desert community are identified; their total energy requirements are estimated and then the capability of available solar potential to meet these energy needs is calculated. A sustainable energy generation model is devised to attain the objective of power generation and potable water production. The processes of solar power generation, desalination and storage systems are built in the proposed model. The sustainable development process is based on the utilization of renewable energy, self-contained nature of energy generation system and environment-friendly nature of power and water production.

Keywords: sustainable energy development; solar energy utilization; desert development

1. Introduction

The main problems for human and livestock population living in the deserts are water scarcity, food unavailability and barren lands. The desert communities therefore move from one place to another in search of food and water. Rainfall is the only source of freshwater in deserts. However, the rains in most of the deserts are less than 100 mm (Muneer and Asif 2005). Due to the persistence of these problems, the standard of living of desert communities is poor (United Nations Environment Programme and Stockhome Environment Institute 2009).

A case study of the deserts Thar, Thal, Cholistan and Chaghi Kharan located in Pakistan, South Asia, is carried out. The areas of these deserts are: Cholistan (2.6 Mha/26,000 km^2), Thal (2.3 Mha/23,000 km^2), Thar (2.2 Mha/22,000 km^2) and Chaghi Kharan (1.8 Mha/18,000 km^2) (Kahlown 2004, Shaikh 2011). The population of these deserts is 1.59 million approximately. Since the basic amenities of freshwater and electricity are scant in these deserts, these deserts' communities face difficulties in getting pure water (Kalim *et al.* 2005, Rosemann 2005). The underground water at these deserts is mostly saline and is not fit for human and livestock drinking

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(Wajahat 1986, Ayub and Butt 2005). The climate is tropical in these regions. Rainfall is the only source of freshwater, which occurs during monsoon period from July to September every year (Kahlown 2004).

Due to the unavailability of water supply system, unhygienic means of drinking water are used in these deserts. The rainwater is collected in the storages called tubas, which are damaged due to seepage and evaporation during summer season (Agrotech 2009). Therefore, the desert communities lead miserable life. Further, these desert areas are lagging behind adjacent areas in the developmental activities.

Fossil-fuelled power generation and desalination processes are an undesirable option for these deserts, because even high efficiency combined cycle natural gas/coal-fired power plants and natural gas-powered plants costs are high. Moreover, these plants release large amounts of CO_2 during the power generation and desalination processes. Also, the reserves of fossil fuels are limited due to depletion (Shafiee and Topal 2009). Therefore, the future dependence on these sources is a risk, and their size could be reduced by changing the nature of energy to renewable especially solar (Douggar 1991). Moreover, the use of mobile/rental coal/natural gas-powered plants are not affordable for these desert sites. Further, every country that signed up to the Kyoto treaty is bound to decrease the level of CO_2 emissions. However, solar power and desalination plants could facilitate in controlling the CO_2 emissions (Barrett 1998).

Solar power generation could, therefore, be utilized in the deserts in solar-rich countries, as it is an economical and environmental-friendly power generation process. The solar power plants neither emit toxic pollutants nor impact adversely upon human health or flora and fauna. As a result, electric power generation and emissions costs can be optimized due to the use of emission-free and zero fuel solar energy. The construction of small, medium and large solar power plants in deserts could facilitate the utilization of high solar potential and low opportunity desert land (Lofken 2010). Solar power plants require fewer infrastructures in comparison to fossil-fuelled thermal power generation. However, one-time capital equipments and installation costs are incurred, which could become economical in the long run. The solar desalination reverse osmosis process could be utilized, as the total energy requirement is below 3.5 kWh per tonne of water desalination (Ejjeh and Awerbuch 2009).

The utilization of a small fraction of solar power over these deserts is capable to produce the required amount of energy and it can bring the process of sustainable development and prosperity in these deserts (Mirza *et al*. 2003, Darwish and Al-Najem 2005, Shah and Zhang 2010). Since these deserts have low population density and have little or no agricultural potential, low opportunity cost land could be utilized for solar photovoltaic or thermal power generation (Wheeler and Ummel 2008). Self-contained solar-powered energy generation and production processes can bring the processes of development and commercialization in parallel.

A sustainable energy generation model can utilize available solar power and desert land for the production of electric power and pure water in the deserts of Pakistan. The main inputs of this model are underground brackish/aquifer water and solar energy. The proposed model is capable of resolving the problems of desert communities including potable water, electricity and soil infertility. The proposed sustainable energy generation model for deserts is illustrated in Figure 1.

There are three stages of energy generation and production. In the first place, solar power generation is obtained from the solar energy potential available in these deserts that is $1000\,W/m^2$ for 8 h ($28.8\,MJ/m^2/day$) (Alternative Energy Development Board 2011). Desalination of underground aquifer saline water can be attained in the second stage. Reverse osmosis process could be utilized for the desalination of brackish water. Solar thermal and photovoltaic storage system are provided in the model to store electrical power and the heat produced and in the day for round the clock sustainable electric power and pure water production. The estimated amount of electric power and freshwater that can be produced at these sites is estimated in Figures 2 and 3 and in Tables 2 and 3.

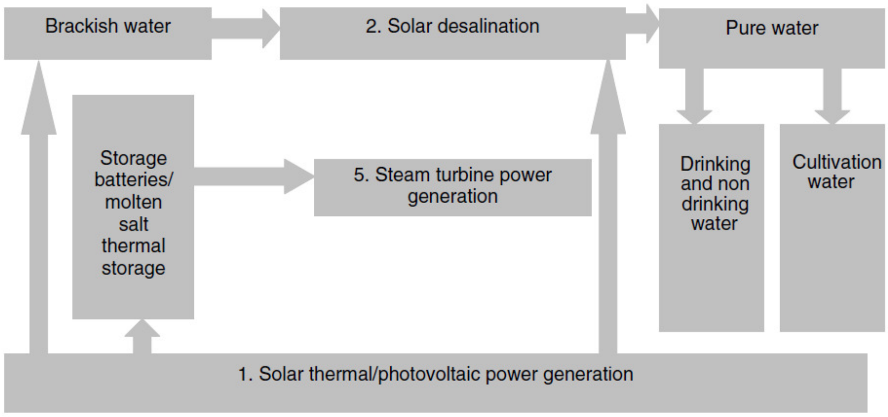

Figure 1. Sustainable energy generation model.

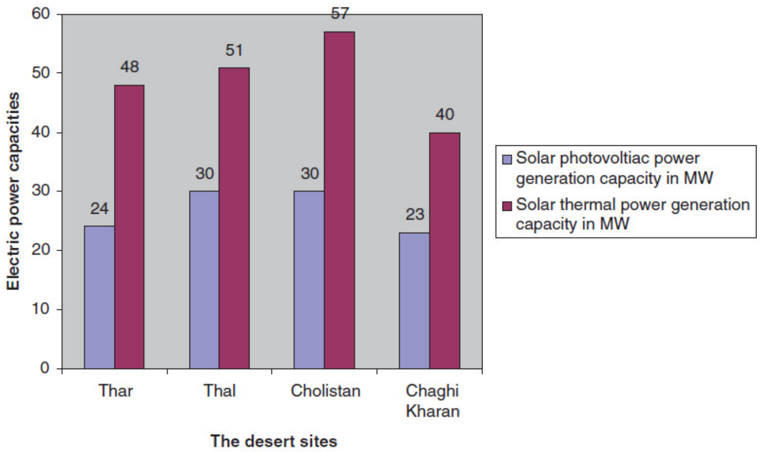

Figure 2. Estimated power generation capacities over 1% desert potential utilization.

2. Methodologies

Demographic analysis, need analysis, mass and energy balance and energy model analysis are carried out for the identification of basic needs of a typical desert community, estimation of energy equivalent and for the demonstration of the capability of available solar potential to meet energy needs sustainably.

2.1. *Demographic analysis*

In the demographic analysis, the nature of the population living in these deserts, their average size and the number of communities living in these deserts are reviewed. The average size of a typical desert community is taken as 500. The demographic and geographical data of Thar,

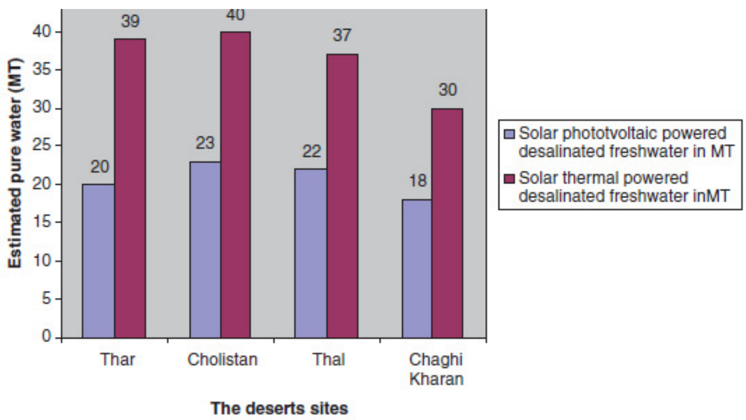

Figure 3. Estimated potable water production over 1% desert solar power utilization.

Thal, Cholistan and Chaghi Kharan deserts are referred from the available literature on desert communities in Pakistan

2.2. *Need analysis*

Based on the assumption that drinking water amounts 31 per person per day and non-drinking water amounts 0.344 tonne per dwellings per day, the total water consumption per day of desert community is estimated (WCC 2011). The total wheat is calculated based on the daily consumption per person per day; in Pakistan, it is 0.438 kg (Mukhtar and Ilyas 1989). Likewise, the rice consumption per person per day is based on the consumption of 0.025 tonne (PCRSE 2011). The total pulses per person per day are 0.008 tonne (Ahmad 2008).

The required amount of pure water for the cultivation of wheat is calculated based on 2548 tonnes per tonne of wheat produced (Mekonnen and Hoekstra 2010). Similarly, the quantity of cultivation water for rice is computed based on 1642 tonnes per tonne of rice (Chapagain and Hoekstra 2010). Finally, the amount of cultivation water for pulses is estimated based on 4000 tonnes per tonne of pulse (Ashraf Zahid 2008).

Total electric power consumption for a desert community is based on *per capita* electricity consumption; in Pakistan, it is 1.20 kWh per person per day (Energy Statistics 2006–2007). The total electric power for desalination is computed based on the total amount of pure water to be desalinated including drinking, non-drinking and cultivation water based on 3 kWh per tonne of desalinated pure water (Darwish and Al-Najem 2005).

2.3. *Mass and energy balance*

In this section, the total amount of energy equivalent required to meet total desert needs is calculated in MJ, so that the prospects of the generation of the same amount of energy can be evaluated. The total energy requirement is shown in Table 1.

Table 1. Desert community need analysis and total energy requirement.

Total drinking, non-drinking water per day and total water for the cultivation of wheat, rice and pulses for 500 people/day (tonnes)	Total drinking water (tonnes)		Total non-drinking water (tonnes)	Total cultivation water for wheat (tonnes)	Total cultivation water for rice (tonnes)	Total cultivation water for pulses (tonnes)	Total drinking, non-drinking and cultivation water (tonnes)	
	1.5		43	407	41	32	524	
Total power consumption for the desalination of water for drinking, non-drinking and the cultivation of wheat, rice and pulses for a community of 500 people	Total electric power consumption per day (kWh)	Total energy consumption for the desalination of drinking water (kWh)	Total energy consumption for the desalination of non-drinking water (kWh)	Total energy consumption for the desalination of cultivation water for wheat (kWh)	Total energy consumption for the desalination of cultivation water for rice (kWh)	Total energy consumption for the desalination of cultivation water for pulses (kWh)	Total energy (kWh)	Total energy (J)
	585	4.5	129	1221	123	96	2158	$60,354,253 \times 10^6$
Total energy (kWh) and power ($MJ/m^2/day$) and total desert land (m^2 and km^2)	Total energy in MJ		Average energy (MJ/m^2)	Solar conversion efficiency	Average electrical energy (MJ/m^2)	Total desert land (m^2)	Total desert land (km^2)	
	7769		0.001	13%	0.00013	59,761,538	59.76	

3.2. *Total solar power generation potential*

The total energy for the water and power generation needs per day for a 500-person desert community is estimated as 7769 MJ. It is possible in these deserts to produce the same amount of energy by utilizing the available solar energy falling over the low-opportunity-cost desert land area of 59.76 km^2. The estimated solar photovoltaic and thermal power generation capacities are demonstrated in Tables 2 and 3 and Figures 1 and 2.

However, at the preliminary stage, the utilization of total solar potential of these desert lands could be delayed due to time and financial constraints. Therefore, the potential of 1% desert solar power utilization is estimated, as shown in Figure 2.

3.3. *Freshwater production potential*

The major portion of the solar power produced at these deserts can be utilized for the desalination of underground aquifer water for freshwater production. The estimated amounts of freshwater that could be produced at these deserts are computed in Table 3. The amounts of desalinated water that could be produced by the utilization of 1% desert solar power are estimated, as highlighted in Figure 3.

4. Conclusions

The nomadic people occupying the deserts Thar, Thal, Cholistan and Chaghi Kharan currently suffer from a lack of both clean water and electric power, with consequent adverse impacts not only on food production and sustainability of life but also on the scope of making better use of desert areas for development purposes.

The potential for the production of electric power has been shown to be quite high. Preliminary results indicate that the electric power and total freshwater requirements for a 500-person desert community could be met by the utilization of solar potential falling over the desert land area of 60 km^2, which is very small in relation to the availability of large spaces in the desert environment. There would be an added environmental advantage in that the development of the deserts would not be dependent upon the increased use of fossil fuels. If desert land areas in excess of that required for the support of communities were to have solar renewable energy production facilities installed, then the desert could become renewable energy hubs, offering sustainable employment for the people of the desert communities.

Considerable challenges, however, exist in the realization of this potential for improvement. These include lack of institutional infrastructure and other resource issues for which incentives and concerted efforts towards resolution are required from a range of stakeholders including the international donor agencies, local government, energy professionals, academicians and water and power industry experts.

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АКАДЕМИЯ НАУК РЕСПУБЛИКИ УЗБЕКИСТАН

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THE IMPACT OF DESERT SOLAR POWER UTILIZATION ON SUSTAINABLE DEVELOPMENT

This paper evaluates the prospects of developing a solar based desert economy in the deserts of solar-rich countries. The potential deserts are analysed to study their positive impact on the sustainable development processes in these regions. The sustainability of the processes is established on the basis of self-contained nature of energy generation, environmental emission reduction and desert land reclamation.

1. Introduction

A solar energy driven desert economy mechanism is presented in this paper. The primary inputs are solar energy, brackish water and desert land. Freshwater and electricity approaches are built in the proposed mechanism. Three levels of generation and production processes are built in the proposed mechanism. An important aspect of the system is that it has the potential to bring development in these regions and could make them on a par with the residential areas. The deserts' solar energy utilisation mechanism is illustrated in fig. 1.

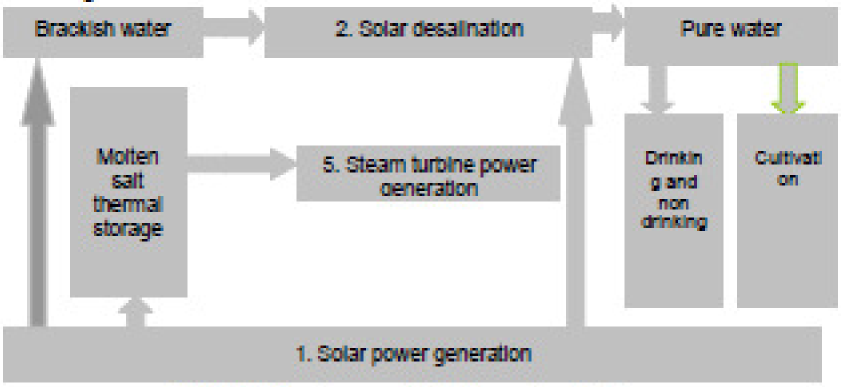

Fig. 1. The desert community development mechanism.

2. Methodologies

The assessment of the solar potential of the deserts of Sahara, Great Sandy, Takla Makan, Arabian, Atacama and Great Basin (based on 8% solar to electricity efficiency) is made to estimate the possible amounts of freshwater and electric power production. A solar energy costs analysis, based on empirical data is also carried out to determine the cost benefits of solar powered power generation and freshwater production.

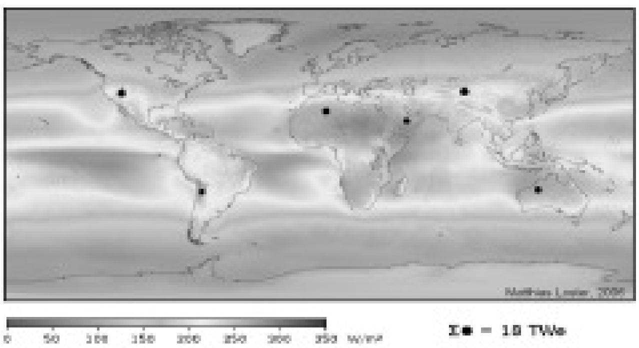

Fig. 2. Solar map showing six black dots areas that are capable to produce electric output of 3 TW each [1].

2.1. Assessment of solar power generation in the deserts.

It is estimated that the solar photovoltaic power generation plants are more efficient for the solar-rich desert regions as it produces electricity directly from the sun. For example, it is estimated that the photovoltaic systems installed in the areas indicated by the dark disks on the solar map, illustrated in fig. 2, could provide the average total electric output of these six disc areas is 18 TW, assuming conversion efficiency from sunlight to electricity of 8 percent. Solar insolation for the areas falling in these blotted areas (deserts) is between 200 and 350 W/m^2 (3.5-7 kWh/m^2/day) [1].

This corresponds to an energy output of 13,567 million tonnes of oil equivalent (Mtoe) per year [1]. Therefore, more than world's total energy supply (the world's total primary energy supply in 2006 was 11,741 Mtoe) could be produced in these deserts [7]. The sizes and the solar irradiation of the deserts of the black dots shown on the map in fig. 2 are given in tab. 1.

Table 1

List of locations, land area requirements and solar availability [1] and [2]

Location / Desert	Desert Size km^2	Irradiation W/m^2
Africa, Sahara	9,064,960	260
Australia, Great Sandy	388,500	265
China, Takla Makan	271,950	210
Middle-East, Arabian	2,589,910	270
South America, Atacama	139,860	275
U.S.A., Great Basin	492,100	220
S. Asia, Thar,	246,000	130

The utilization of even a small fraction of desert power could change the energy scenario. Therefore, concerted efforts are required to move closer to this direction to bring sustainable development in these regions.

Table 2

Solar power generation capacities of the desert

Percentage deserts' land	10	20	30	40	50	60	70	80	90	100
Sahara, Africa										
Desert area km2	906496	1812299	2718102	3623905	4529708	5435511	6341314	7247117	8152920	9058723
Electric power capacities (GW)	19	38	57	76	95	114	133	152	171	190
Great Sandy, Australia										
Desert area km2	3885	7770	11655	15540	19425	23310	27195	31080	34965	38850
Electric power capacities (GW)	0.082	0.164	0.246	0.328	0.41	0.492	0.574	0.656	0.738	0.82
Takla Makan, China										
Desert area km2	27195	54390	81585	108780	135975	163170	190365	217560	244755	271950
Electric power capacities (GW)	0.456	0.913	1.37	1.827	2.284	2.741	3.198	3.655	4.112	4.569
Arabian, Middle East										
Desert area km2	258991	517982	776973	1035964	1294955	1553946	1812937	2071928	2330919	2589910
Electric power capacities (GW)	6	12	18	24	30	36	42	48	54	60
Atacama, South America										
Desert area km2	13986	27972	41958	55944	69930	83916	97902	111888	125874	139860
Electric power capacities (GW)	0.307	0.615	0.923	1.231	1.539	1.847	2.155	2.463	2.771	3.079
Great Basin, USA										
Desert area km2	49210	98420	147630	196840	246050	295260	344470	393680	442890	492100
Electric power capacities (GW)	0.866	1.73	2.594	3.458	4.322	5.186	6.05	6.914	7.778	8.642
Thar, S. Asia										
Desert area km2	24600	49200	73800	98400	123000	147600	172200	196800	221400	246000
Electric power capacities (GW)	2.88	5.76	8.64	11.52	14.4	17.28	20.16	23.04	25.92	28.8

2.2. Solar energy costs analysis.

The trends in the fixed and variable costs of solar energy, based on the data of market research and consulting companies, are analysed under this section.

3. Results and analysis

The preliminary results are promising. Huge amounts of freshwater and electric power could be produced in these deserts, which could supplement the existing power generation capacities and freshwater supply in these regions in an environmentally friendly manner.

Total Power generation potential.

Though these deserts are rich in solar energy for most of the year due to an average normal irradiance of 250 W/m^2 /day available in these deserts yet these are largely uninhabited, and have little or no agricultural potential. This solar-rich and low opportunity cost desert land could be utilised for sustainable development programmes [3], [5], [6]. The amounts of power generation are estimated on basis of by solar photovoltaic efficiency (8%). is illustrated in tab. 2.

However, it could be difficult at the preliminary stages of planning and implementation to utilize the whole desert land due to the technical and economical reasons. Therefore a small fraction of these deserts, for instance solar potential of one percent of the land could be utilized. The solar photovoltaic and thermal power generation potential that could be generated over the utilization of one percent of deserts' land is illustrated in fig. 3.

Table 3

Freshwater production potential of potential deserts

Percentage of deserts land	10	20	30	40	50	60	70	80	90	100
Sahara, Africa										
Electric power capacities (GW)	19	38	57	76	95	114	133	152	171	190
Freshwater capacity (MT)	6333	12667	19001	25335	31669	38003	44337	50671	57005	63339
Great Sandy, Australia										
Electric power capacities (GW)	0.082	0.164	0.246	0.328	0.41	0.492	0.574	0.656	0.738	0.82
Freshwater capacity (MT)	27	54	81	108	135	162	189	216	243	270
Takla Makan, China										
Electric power capacities (GW)	0.456	0.913	1.37	1.827	2.284	2.741	3.198	3.655	4.112	4.569
Freshwater capacity (MT)	456	912	1368	1824	2280	2736	3192	3648	4104	4560
Arabian, Middle East										
Electric power capacities (GW)	6	12	18	24	30	36	42	48	54	60
Freshwater capacity (MT)	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
Atacama, South America										
Electric power capacities (GW)	0.307	0.615	0.923	1.231	1.539	1.847	2.155	2.463	2.771	3.079
Freshwater capacity (MT)	102	204	306	408	510	612	714	816	918	1020
Great Basin, USA										
Electric power capacities (GW)	0.866	1.73	2.594	3.458	4.322	5.186	6.05	6.914	7.778	8.642
Freshwater capacity (MT)	287	577	867	1157	1447	1737	2027	2317	2607	2897

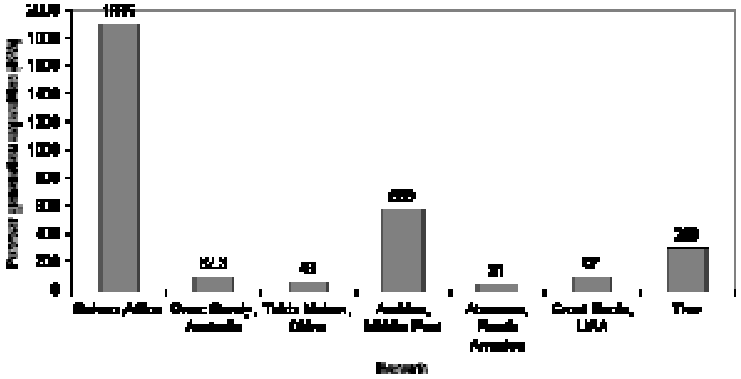

Fig. 3. Graph showing estimated electricity generation capacities in GW.

Freshwater production potential.

The electric power potential generated in these deserts could be utilized for the desalination of underground aquifer water. The production of freshwater in these deserts could promote a local economy based on agricultural development. The estimated amounts of freshwater that could be produced by the utilization of 1-100% of power produced are illustrated in tab. 3.

As explained, there is huge potential of freshwater production in these deserts. The amounts of freshwater that could be produced per day by the utilisation of solar energy falling over one percent desert power are highlighted in fig. 4.

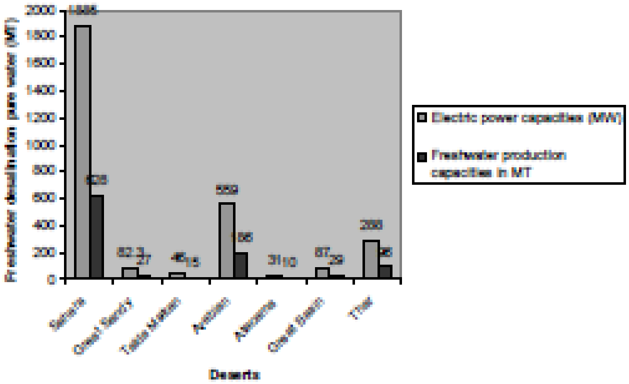

Fig. 4. Graph showing total amounts of freshwater production in MT.

Costs analysis.

A downward trend is observed in solar panel prices. The initial cost of solar panels can be extended over 25 years, and by the passage of time, the running cost is optimized. The retail prices of solar panels in Europe and the United States are taken, which have reduced remarkably in the period 2001 to 2010 [4]. The decreasing trends in the prices of solar panels in Europe and the United States are graphed in fig. 5.

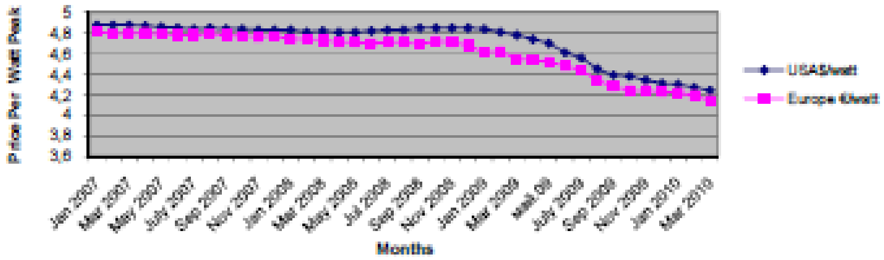

Fig. 5. Graph showing solar panel reduction index showing downward price trend in Europe and United States in US dollars and Euros [4].

The "Solar Electricity Index" is derived on the basis of the data obtained from the Solarbuzz consultancy report. The index shows a downward trend of solar electricity, as illustrated in fig. 6. The Index is based on an average of 5.5 hours sunshine per day, which includes the areas in Saharan belt, southern Africa, Saudi Arabia, central Australia, Peru and Bolivia, and is based on a survey of 70-80 companies retailing solar electric products [4].

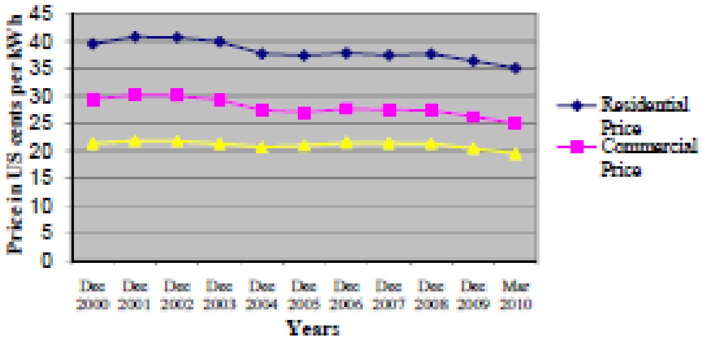

Fig. 6. Graph showing solar electricity price index showing downward trends for domestic, commercial and industrial categories [4].

The cost analysis of the solar cell panels and solar electricity generation reveals that these costs have brought down in the last decade, and on production of economies of scale further decrease in the costs could be expected.

4. Discussions and conclusion

The analysis of the feasible desert sites reveals that these sites are blessed with the inputs of abundant solar energy, underground aquifer water and large land spaces. Most of them have certain advantages; for instance the USA is a leader in solar power generation technology. China is the most populous country in the world, whilst Australia is capable of developing arid areas, and Saudi Arabia has the strength to realise the implementation of desert economy.

The proposed methodologies could be utilized for the development of these desert regions. It could provide them a clean, reliable and adequate energy system. The new processes of development and prosperity could based on solar energy sources could be launched. It could contribute to diminishing the dependence on fossil-fuelled economies. The problems of energy scarcity, affordability and environmental emissions could be resolved in the long run.

The transition period may last over a considerable period of time, possibly a decade or longer. The following measures may facilitate the transition from a fossil-fuelled to a solar powered desert community development.

- Formulation of short, medium and long term strategies, for the utilization of desert power in potential desert sites.
- Arrangement of joint research projects for establishing the feasibility of solar-powered desert development projects.
- Allocation of funds in the development budgets for the construction of solar-powered desert development projects in the locations mentioned in the analysis section.
- Subsidies on manufacturing and purchase of materials and equipment used in the solar desalination, solar power generation industries.
- Arrangements for seeking international cooperation at the preliminary stage to finance desert development projects.

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The author acknowledges the contribution of his parents and family members whose support and encouragement enabled him to attain excellence in higher studies. Special thanks are offered for the level of technical support and guidance provided by the peers and associated organization in the pursuit of the research work.

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Appendix C-Conference Papers

1. Sadiq Ali Shah and Yang Zhang, "Hybrid Energy Based and CO_2 Sequestration Capable Desert development", International Conference on Energy Systems Engineering (ICESE 2010), held from 25^{th}- 27^{th} Oct, 2010 at Islamabad, Pakistan.

2. Sadiq Ali Shah and Rodger Edwards, "Strategies for the sustainable provision of electrical power and water supply for desert communities", Tyndall-SCI PhD conference, 30th–31st March, 2011, Manchester.

3. Sadiq Ali Shah and Yang Zhang, "Optimum energy based desert development model", "Postgraduate Research Conference 2010", held on 01-06-2010, at School of Mechanical, Aerospace and Civil Engineering, The University of Manchester.

4. Sadiq Ali Shah and Yang Zhang, "Solar powered and CO_2 Sequestration Capable Desert Economy", held on 01-07-2009, School of Mechanical, Aerospace and Civil Engineering, The University of Manchester.

5. Sadiq Ali Shah, "Energy scenario and options for China" in China Postgraduate Network Conference 2009, April 23-24, 2009, Luther King House, Manchester.

III- Group Discussions

11. EU-GCC Clean Energy Network Second Group Discussion Meeting, 11-12^{th} May, 2011, Thon Briston Stephanie, Brussels, Belgium.

Hybrid Energy Based and CO_2 Sequestration Capable Desert Development

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Abstract- Self-contained energy production and utilization methods are analyzed for the supply of basic amenities in deserts. A combined strategy of hybrid energy sources of solar and coal is devised in this energy model. The processes of desalination, power generation, oxyfuel combustion and CO_2 sequestration are proposed for the production of freshwater and electricity. CO_2 produced by oxyfuel power generation can be sequestrated. The energy model can be utilized in the desert areas of solar and coal-rich countries, and since Pakistan is such an example country the deserts of Thar, Choolistan, Thal and Chaghi-Kharan are suitable sites for the proposed model. The freshwater produced from brackish water or pumped seawater and the electricity generated from solar energy and coal will be very valuable for desert reclamation. The feasibility of the model is established by taking into account the energy savings, environmental emissions, production costs and sustainability limits.

Key Words: Solar energy, CO_2 sequestration, desert development

[1] Corresponding Author

Introduction

Capability of primary energy sources is essential for a sustainable growth in all sectors of the economy. Energy scarcity, environmental pollution and increasing fuel prices are all problems in terms of energy production in Pakistan. [4] Pakistan's total primary energy supply during the fiscal year 2007– 2008 was 62.88 MTOE (million tons of oil equivalent. [2, 3] The per capita energy consumption (3894 kWh) and per capita electricity consumption (350kWh) in Pakistan is even lower than the average energy consumption in developing countries and developed countries. [1] Despite being a solar and coal-rich country, Pakistan faces the acute challenges of an energy deficit and the primary energy supplies are not enough to meet the present demand. The country's oil and gas reserves are depleting at a rapid rate, resulting in an increase in the import of crude oil.[2] The country is facing serious energy shortage problems because the demand for primary energy in Pakistan has increased considerably over the last few decades. Due to a dependence on oil and gas, the country is also facing serious threats of global warming, for which environmentally-friendly indigenous energy sources need to be developed and popularized. The nature of primary energy sources are highlighted in figure 1:

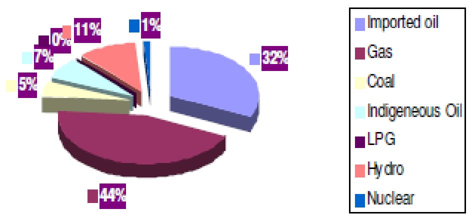

Fig.1. Proportions of primary energy supplies in the energy mix in Pakistan in the year 2007-08 [8]

The figure reveals the large share of oil and gas, followed by hydro and coal. [5, 6] The current energy scenario reveals a small share of renewable energy sources and a lack of alternative energy utilization methods.

The imbalance in energy-mix can be realized from the fact that the major electricity generation sources are conventional; such as oil and gas, with a small share of hydel and nuclear, as highlighted in figure 2:

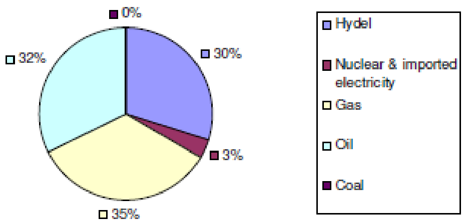

Fig.2. Electricity generation capacities by energy source in the year 2007-08 [11]

[7] Despite the fact that the country has solar potential compared to limited conventional energy resources, the share of renewable energy is less than 1%. Therefore, it is crucial to devise a diverse energy strategy that is based on diminishing dependence on fossil fuels and explores sustainable energy resources. In this regard, the utilization of indigenous hybrid (solar and coal) energy sources in deserts seems to be a feasible option for supplementing electricity generation and freshwater production, along with the development in these under-developed areas. Hybrid systems are recognised worldwide and are used internationally. [12] 24-hour power generation and freshwater production could be achieved at a potentially low average cost and with low emissions, by utilization of sunlight during the day and coal/l gas at night to run the same power block. [13] Because of its sustainable nature, hybrid CSP-gas technology is proposed for the MENA (North Africa and Middle East) region.

Therefore, with the aim being to launch a sustainable energy development process in the deserts of Pakistan, hybrid energy (solar-coal) based and a CO_2 sequestration capable desert energy model is developed, which is illustrated in figure 3. The ultimate beneficiaries of this model are the solar and coal-rich countries, and Pakistan could become one of its beneficiaries. The primary inputs of this model are solar energy, seawater, air and coal.

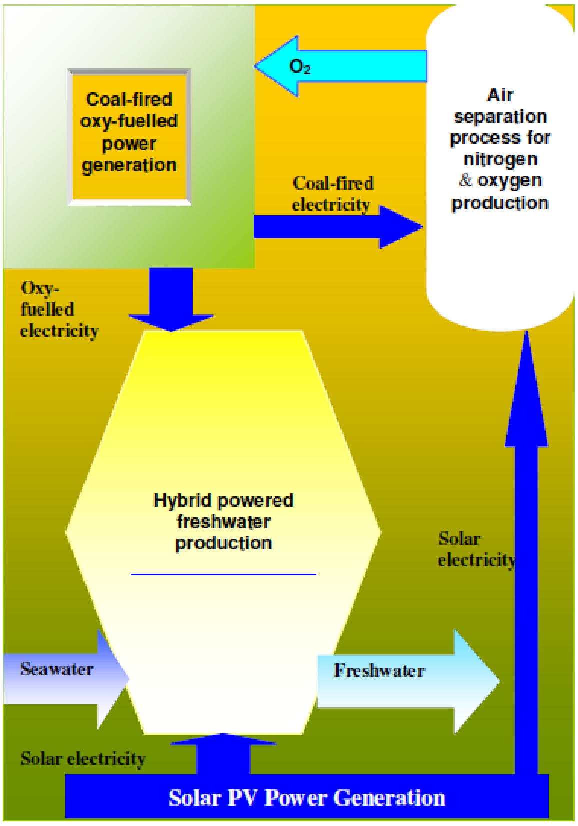

Fig.3 Illustration of the desert development model

An important aspect of this energy model is the self-contained nature of power generation, which could facilitate the process of energy supply in remote places without incurring the expenditures on transmission systems, and it also eliminates transmission losses. Electricity generation, freshwater production and basic infrastructure can be improved by the development of these self-contained energy systems, thereby allowing the processes of development and commercialization to work in parallel. The government's efforts to utilize hybrid energy sources in the supply of freshwater and electricity to under-developed areas in Pakistan can be aided by the utilization of this model. [2] The model can be implemented by the Alternative Energy Development Board (AEDB), which is engaged in attaining a target of 10% of the total electricity generation from renewable energy sources by the year 2015. The desert development model could also be utilized for a gradual switch over to renewable energy sources to meet the energy requirements of the country in an efficient and effective manner.

[12] The intense solar radiation received by the deserts of Pakistan, together with lignite coal reserves in bulk at desert locations, means that there is a low opportunity cost for utilization. [16] In this regard, desert regions in

the Punjab, Sindh and Baluchistan could become feasible potential desert sites. These are the Thar, Thal, Cholistan and Chaghi Kharan deserts.

Methodologies

There are three levels of energy generation and production processes in the proposed desert development model. At the first level, power generation is attained by solar photovoltaic panels and by oxyfuel power generation in the evening and nights. In the second stage, freshwater is produced by solar electricity during the day and by coal-fired, oxy-fuelled, electricity in the off-solar hours.

The purpose of using oxyfuel combustion is to ensure the reduced amount of fuel (coal) and to attain a higher flame temperature. Moreover, the process is environmentally-friendly, as it produces 75% less flue gases than air fuelled combustion. Since the content of oxygen in the oxyfuel combustion process is 95%, the resulting emissions are carbon dioxide and water. Carbon dioxide emitted by the process can then be sequestrated in the third stage by injection into the deep sea at a depth of 100 m to convert it to carbon dioxide hydrate. The drain water of oxyfuel power plant can be converted into freshwater by using a water treatment plant.

In view of the availability of indigenous solar energy and coal reserves, a hybrid (a mix of both energy sources) energy source is proposed to meet off-solar energy needs for electricity and freshwater production. The combined strategy of using solar energy and coal can also lead to round-the-clock power generation and freshwater production processes.

Viability of a solar powered processes

[1, 15, 22, 23] Pakistan is a solar-rich country, and is blessed with abundant solar radiation due to its ideal location in the sunny belt. As such, the country could benefit from solar energy utilization technologies. [15] It has been estimated that over the total geographical area (i.e.796,095 km^2) the total available solar energy potential is 5.23 PJ/m^2 per year. [1, 11, 24] Pakistan receives (on over more than 95% of its area) an average solar radiation of 5–8kWh/m^2/day with an 85% persistence factor. [7] According to the figures, the annual incident solar radiation in the country is in the range of 1900–2200 kWh/m^2. [15, 26] The annual mean values of insolation lie between 16.0-21.0 MJ /m^2/day with 19.0 MJ/m^2/day over most parts of the country. [6] The mean values of insolation vary from 12-13 MJ/m^2 /day in December/January to 25-26 MJ/m^2/ day in June. [27] These variations are from 16 to 25 MJ/m^2/day in the southern regions.

The South Western province of Baluchistan and the North Eastern part of Sindh also offer excellent conditions for harnessing solar energy. [23] The Energy Administration confirms that the daily solar energy potential for Pakistan is 5.3 kWh/m^{2}day. The map showing the number of sunny days in the regions of Pakistan is shown in figure 4.

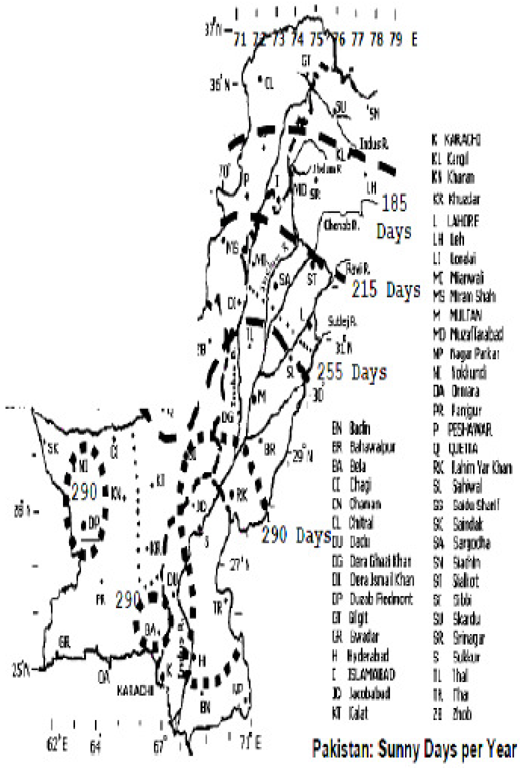

Fig.4. The Map of Pakistan Showing Dashed Lines as Sunny Days per Year [**28**]

[10, 1] Therefore, solar photovoltaic (SPV) technology is a feasible option for providing clean energy to the deserts and remote areas, and could save the cost of transmission lines to such locations. Solar radiation data of the proposed desert sites can be also collected using satellite based solar radiation data. [23] The satellites provide global maps of irradiance of up to 1 km resolution several times per hour. [30] The photovoltaic power generation method is proposed because of the fact that it is recognised worldwide, as in the United States, large terrestrial photovoltaic power stations (about 100 MW capacity) operate as stand-alone.

The photovoltaic cells produced locally in Pakistan can be utilized for use in the proposed desert sites. [32] The

National Institute of Silicon Technology, Pakistan, which has a capacity for assembling and manufacturing 3 million solar cells, can become a reliable supplier of solar photovoltaic cell panels to these desert sites, along with the National Engineering and Science Commission (NESCOM) and Solar Energy Centre (SEC), which are also engaged in the production of photovoltaic panels and the designing of solar thermal appliances.

The electricity output per square meter at these desert sites can be increased, if high efficiency solar cells are utilized. In this regard, a close coordination with scientific and research organization in Pakistan, which are engaged in the research on efficiency of solar cells, may bring the desired results. [29] The Pakistan Council for Renewable Energy Technologies (PCRET), which has achieved 13% efficiencies in round plainer solar cells with a single layer antireflection coating, can supply these high efficiency solar cell panels to the desert sites.

[9, 31] The power density of a solar cell at the deserts can be estimated by obtaining insulation data for any hottest place in Pakistan, for instance the city of Jacobabad. [16] The average annual solar radiation for Jacobabad is 489 W/m^2. If the (solar–electricity conversion) efficiency of a common silicon solar PV cell is assumed at 20 percent, then the power density that can be extracted from the incident solar flux at any location in Pakistan would be:

$$489 \times 20\% = 97.8 \text{ W/m}^2$$

[16] Since photovoltaic cells make up two-thirds of the total area of a panel, so a one meter square solar PV panel can generate about 65 watts from the incident flux. In order to produce 100 W of electricity, the required area of a PV panel would be around 1.53 square meters. Therefore, a total of 153,000 PV panels of 100 watts each would be required for the installation of a 10 MW capacity solar photovoltaic power plant. Since the solar radiation in the desert sites is around 489W/m^2, it can be presumed that the volume of solar panels and the area of desert land would be almost the same.

The option of solar utilization is proposed in the desert development model in view of the available solar potential at these desert sites. However it could be difficult at the preliminary stage to utilize the whole area of these deserts, therefore it could be proposed that initially, 1% of the land of these deserts should be utilized, which can still produce considerable amounts of electricity in these areas. The expected amounts of electricity over 1% of the deserts' land is illustrated in figure 5, assuming 20% solar to electricity conversion efficiency.

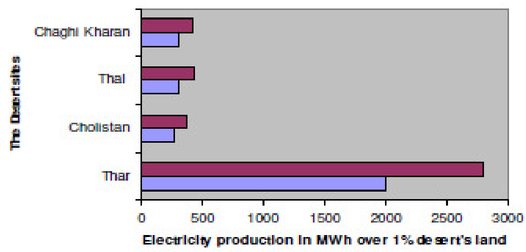

Fig.5.Electricity generation potential over 1% desert land

An important aspect of solar energy utilization is the stand-alone nature of power generation, which makes these systems free from transmission losses, theft and transmission line investment. [11,15,25] Therefore, in order to supplement existing energy sources in Pakistan, the economical and efficient utilization of solar energy in deserts seems to be a viable option in the long run. [11, 6] The desert development model can also be utilized for the supply of electricity to 25,000 villages/settlements besides deserts, where electricity supplies from a national grid and other sources is not possible or is uneconomical. [14, 31] It could also facilitate the reduction of transmission line losses incurred in centralized power generation.

[14, 15] Furthermore, it is well established that PV is a cost-effective technology, its maintenance costs are negligible compared with fuels systems. It also lasts a long time, usually 20-50 years, which makes it more reliable and attractive in power generation. [16] Recent trends in grid-scale power production from PV cells indicate a substantial decrease in costs. Considering the existing cost of PV cell modules in Pakistan, which are in the range of $ 4-7 per watt (including accessories, such as converters, and installation charges) it can be estimated that the cost of solar panel modules for a 10 MW plant, could be up to $40-70million. [10] However, conventional power plants, Ghazi Barotha Dam (hydel power plant) cost Rs. 118 million per MW (US% 2.2 billion) for 1400 MW. [2] The solar cells for the proposed desert sites can be obtained from the subsidiary organization of the government of Pakistan engaged in solar cell production.

Solar panel modules and electricity generation costs have decreased in Pakistan with the passage of time. The single and polycrystalline silicon modules manufactured in Pakistan (at the prices of US$2.90 and $3.25) and amorphous silicon modules (at prices of $2.00-3.00 per watt) can be installed at these desert sites. [2,16] The costs for solar powered electricity in Pakistan are around US $0.20, and the levelised cost of producing electricity at a 10 MW solar PV plant could cost upto 27.2 cents/kWh. Further decreases in solar electricity costs can be attained by production of solar cells on economies of scale.

The electricity produced in these deserts can be supplied to adjacent areas and can be transmitted to the national grids to reduce the existing gap of demand and supply of electricity in Pakistan. The electricity generated in these deserts has the potential to meet the expected demand in 2015 and 2020, which are around 28029 and 41132 MW respectively.

[22] Furthermore, solar powered electricity production is a feasible option, as the power generation is free from maintenance costs and environmental emissions neutralization costs. [33]Therefore, high priority should be given to the utilization of the solar powered desert development model in the desert areas of Pakistan. [7] Due to the solar photovoltaic power generation process, the model can be a more convenient and value-engineered solution to provide electricity for basic needs in the Thar, Cholistan, Thal and Chaghi Kharan deserts.

Feasibility of coal powered processes

The utilization prospects of coal are projected in the desert development model because of the cost effectiveness of this source of energy, and its capability to supplement solar energy in the off-solar hours. Coal could be utilized for an oxyfuel power generation process along with solar power generation to ensure round-the-clock power generation. In the Thar Desert site, the coal can be arranged conveniently, as the desert's lignite coal reserves are 175 billion tonnes. [11] Sub-bituminous coal to Cholistan and Chaghi Kharan desert sites can be arranged from the coalfields of Baluchistan and Punjab.

The coal is an inexpensive and a reliable energy source for these desert sites in Pakistan, as it can be utilized during the evening and night for electricity generation and freshwater production. Around 2.2 kWh electricity can be produced from a kilogram of coal or 2.2 MWh electricity from a tonne of coal. It is estimated by the Thar Coal & Energy Board (TCEB) that the coal reserves at the Thar Desert are capable of meting the energy demand for next 1324 years at the present rate of consumption (83262 MTOE). The small share of coal in power generation, as highlighted in figure 6, can also be increased by the utilization of desert development model.

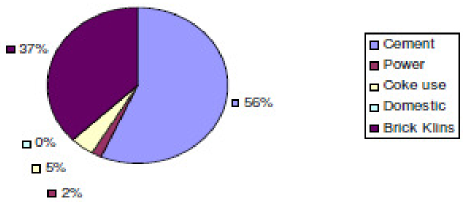

Fig.6. Utilization of coal in industries (2007-08) [11]

[34] The total electricity generation potential of Thar coal is 100,000 MW for 30 years, which is based on an estimated consumption of 536 million tonnes of coal. If 10% of the total Thar coal-powered electricity is utilized every year, it can still resolve the problems of load shedding in Pakistan, and can meet the future electricity demands. It is important to note that the expected demand in 2015 and 2020 are 28029 and 41132 MW, and this can only be attained by supplementing existing power generation capacity. The existing electricity gap in demand and supply in Pakistan (4500 MW) can be bridged up by the utilization of only 2045 tonnes of Thar coal. [31] The electricity generated at these desert sites can be supplied to national grids. It could facilitate an increase in the existing share of coal powered electricity, which is 0.79% of total electricity generation. An important aspect of coal power generation is that it could also bring down the electricity costs in Pakistan due to its indigenous production.

Thar coal can also be utilized to meet freshwater production capacities in Pakistan. The burning of one kg of coal can produce 2kWh of electrical energy, and one tonne of freshwater can be produced on consumption of 3-4 kWh electricity in a solar desalination reverse osmosis process. The expected amounts of coal-powered electricity and freshwater is highlighted in figure 7.

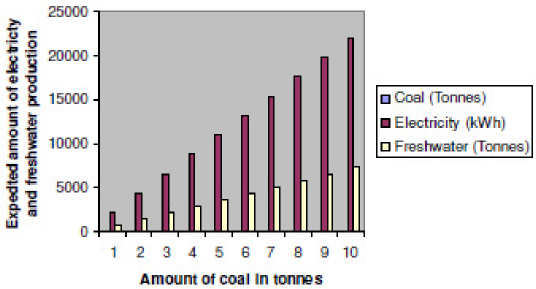

Fig.7. Expected amounts of electricity and freshwater that can be produced by the utilization of indigenous coal

The above graph reveals that the coal-powered oxyfuel power plant can produce considerable amounts of electricity and freshwater. The amount of freshwater produced by a coal-powered reverse osmosis process with one tonne of coal (733 tonnes) freshwater is considerable, and can be utilized for drinking and cultivation purposes.

Prospects of freshwater production

The only method for the management of freshwater resources and sustainable development in the deserts of Pakistan seems to be through desalination of brackish or seawater. By utilization of the proposed model, the residents of deserts can be protected from the hazardous use of saline water. The availability of freshwater could bring prosperity and could boost the local economy in these areas. The residents of Thar, Thal, Cholistan and Chaghi Kharan, could solve the problems of land dryness, and could have a plentiful source of freshwater. The desert sites adjacent to the coastal belt can also be utilized for the desalination of seawater, by pumping seawater to these sites. [35] Solar photovoltaic appliances like water pumps can be utilized for the pumping of seawater to these sites, because of the average daily solar radiation in these places is higher than 3.5 kW/m^2 on a horizontal surface. [22] Seawater desalination processes could also lessen the impact of the rising Arabian Sea level, as Pakistan is one of the countries classified by the United Nations Environment Program (UNEP) program, as being vulnerable to the effects of sea level rise. [37] The coastal belt of 750 kms extending from the Hub to the Gawadar bay and Baluchistan, adjacent to Thar and Chaghi Kharan deserts, can be utilized for seawater desalination.

The experience accumulated by solar desalination plants, already installed at remote locations in Pakistan by the Pakistan Council of Scientific and Industrial Research (PCSIR), can be utilized in this regard. [6] The expertise and the staff of existing plants in the Therparker district (with a capacity of 250 gpd) and a plant at Gawadar (with a capacity of 6,000 gpd) can be helpful during the installation of desalination plants at these desert sites. [37] The Karachi nuclear power plant's seawater desalination plant at Karachi could provide a valuable information regarding seawater desalination.

Preliminary calculations are made to estimate the amount of freshwater that can be produced at the mentioned desert sites. [36] The estimation is based on the electricity consumption rates in a reverse osmosis desalination process. In solar desalination reverse osmosis process one tonne of freshwater can be produced on the consumption of a 3-4 kWh electricity. It is important to note 3-4 kWh electricity at these desert sites can be generated from a 2-3 square meter land. The amount of freshwater that can be produced in these deserts if 1% of the desert land is used, as highlighted in figure 8.

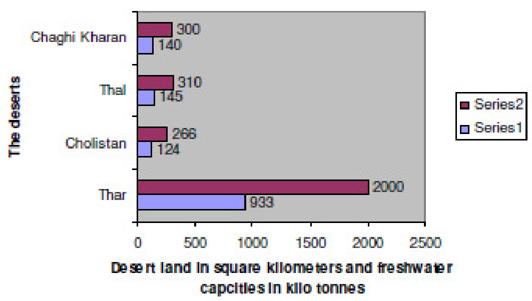

Fig.8. Amounts of freshwater production over 1% of deserts' land.

Since the area of these deserts is quite large, a huge amount of freshwater can be produced at these sites, which can meet the drinking and cultivation needs of the people residing in these areas. The amount of freshwater produced at these desert locations could facilitate the process of sustainable growth in domestic and commercial sectors. The supply of freshwater in these deserts can transform them into oases.

Potential desert sites in Pakistan

Due to lack of water to sustain life, the desert areas in Pakistan are lagging far behind in development activities. [42] According to estimates, 70 million hectares of Pakistan have an arid or semi-arid climate including desert land, and out of 41 Mha of arid areas, 11 Mha falls under the category of main deserts. [43] The population of the arid and semi-arid areas of Baluchistan and Sindh have to depend on underground porous and permeable rock reservoirs because of the meagre surface flows. [26]

Basic amenities, like freshwater and electricity, are absent in the deserts. However, the objective of supplying freshwater and electricity to these deserts can be also be attained by the utilization of coal-powered electricity generation and freshwater production processes. Therefore, Thar, Thal, Chaghi Kharan and Choolistan can be utilized for freshwater and electricity generation. The graphical view of these deserts is depicted in figure 9.

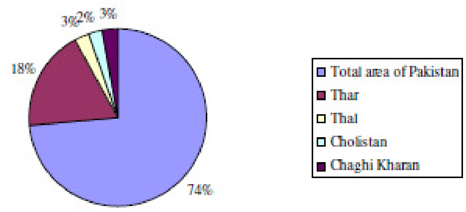

Fig.9 Areas of deserts in Pakistan

The Thar Desert is spread over an area of 200,000 km^2, and its residents suffer from very harsh living conditions due to inadequate availability of freshwater. The Cholistan desert covers an area of 26600 km^2. [42] The Thal Desert covers an area of about 31 000 km^2, and the total area of the Chaghi Kharan desert is 30,000 km^2. The main problem for the human and livestock population is water scarcity, as most of the area is characterized by undulated deserts. [34, 45] The underground water in all these deserts is mostly saline and unfit for human and livestock drinking.[44] Since the water-table is 10 m in Tharparkar and in Cholistan fresh water is at an average depth of 40 m , brackish water can be used to produce freshwater by a desalination process.

Since rainfall is the only source of freshwater source in deserts, the standard of living in these areas is poor due to lack of water storage facilities. A freshwater supply to these deserts using a desalination process of brackish water can resolve water shortage problems in a sustainable manner.[43] In this regard, the groundwater investigations previously carried out by research organisations in these desert regions in Pakistan (to assess the feasibility of freshwater production) can become a valuable source of information.

Moreover, these deserts are almost uninhabited therefore there is less likelihood of environmentally hazards affects on the local population. However, sequestration of carbon dioxide (pre sequestration using oxyfuel combustion and post sequestration by formation of carbon dioxide hydrate) can address the environmental concerns

As already discussed, the solar radiation falling per square meter in these deserts could produce half a tonne of freshwater and 1.4 kWh electricity. Therefore, it can be concluded that 93333, 12413, 14466 and 14000 tonnes of freshwater, and 280000,43400, 42000 and 37200 MWh electricity can be produced in Thar, Cholistan, Thal and Chaghi Kharan, if the full solar potential of desert land is utilized. The supply of electricity and freshwater in these deserts could improve the standard of living of the communities residing in these areas and can boost the local economy.

6. Suggestions and recommendations

The analysis of the desert development model and the potential desert sites reveals that the utilization of the proposed model in the above mentioned desert sites can resolve sustainably the problems of unavailability of freshwater and electricity. Nevertheless, considerable challenges exist in the realization of the objective of desert development, such as resources immobilization, lack of sustainable energy initiatives, lack of awareness, and a lack of institutional infrastructure. Therefore, long term planning is required immediately to realise the dream of desert development. The following measures may facilitate the utilization of a desert development energy model:

- Utilization of solar energy and coal for the production of freshwater and electricity in the deserts.
- Planning the desert development projects on national, provincial and regional levels.
- Promotion of the economic and environmental benefits of the desert the development models to seek funding for these projects..
- Feasibility studies for the development of small, medium and long term desert development projects.
- Allocation of funds in the development budgets for the development of deserts.
- Subsidies for the manufacturing and purchase of materials and equipment used in the solar desalination, solar photovoltaic, brine electrolysis, air separation, oxy-fuel combustion, ammonia synthesis, and urea synthesis processes.
- Arrangements for seeking international cooperation to finance desert economy projects.

Conclusion

Scarcity of freshwater and electricity is a major socioeconomic problem for the desert regions specially and for Pakistan generally. The utilization of the desert development model can resolve these problems by the utilization of indigenous energy sources. Thar, Thal, Chaghi Kharan and Choolistan deserts are suitable sites for the proposed desert development model. Once enough experience has been accumulated, the developed methodology can be implemented in the coastal and rural areas of Pakistan, to generate electricity and to produce freshwater. The proposed desert development process may change the fate of the deserts' communities and would provide them with the basic necessities of life. The development process could also stabilize the national economy and contribute to diminishing dependence on fossil-fuelled economies.

The ongoing process can promote commercialization activities in deserts, the creation of employment opportunities, the diminishing dependence on fossil fuels and a reduction in environmental emissions. The proposed energy model would provide social, environmental and economical changes. A green revolution can be foreseen through the implementation of desert development processes.

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Strategies for sustainable production of electrical power and freshwater in the deserts

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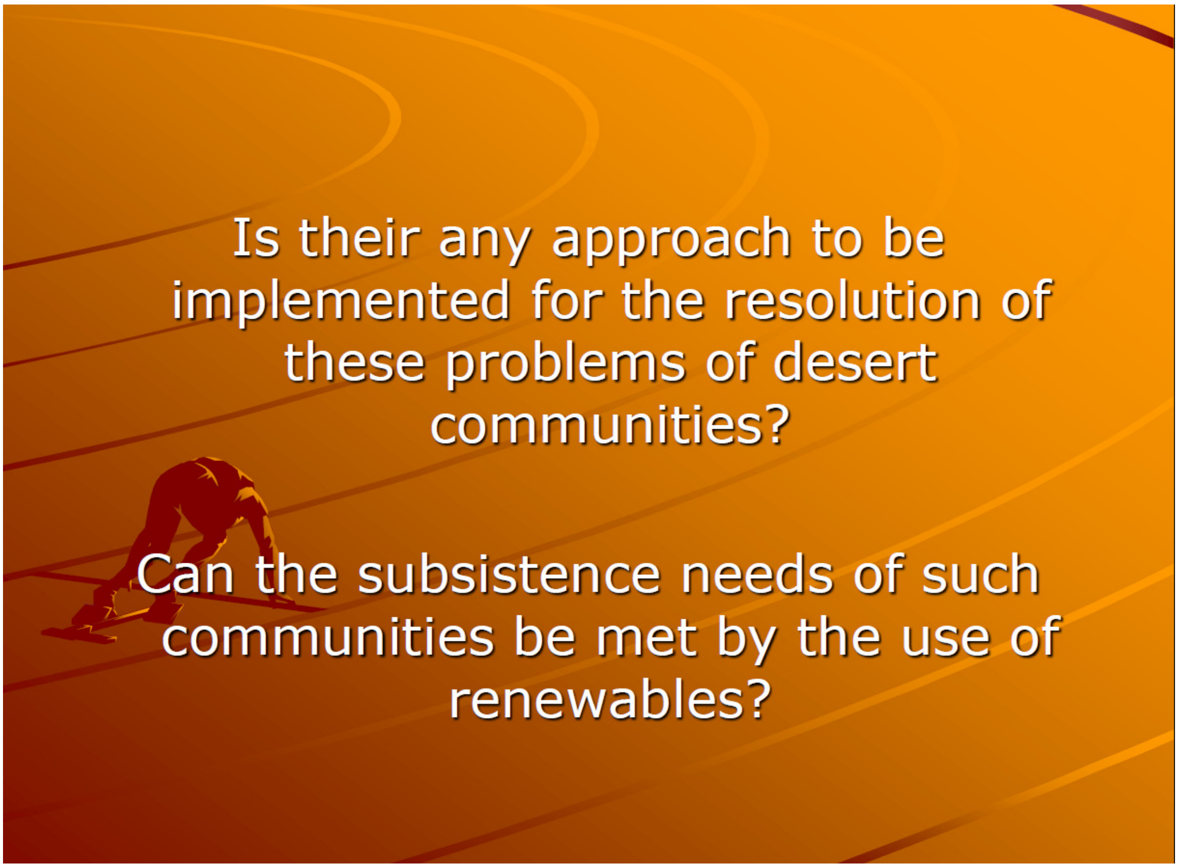
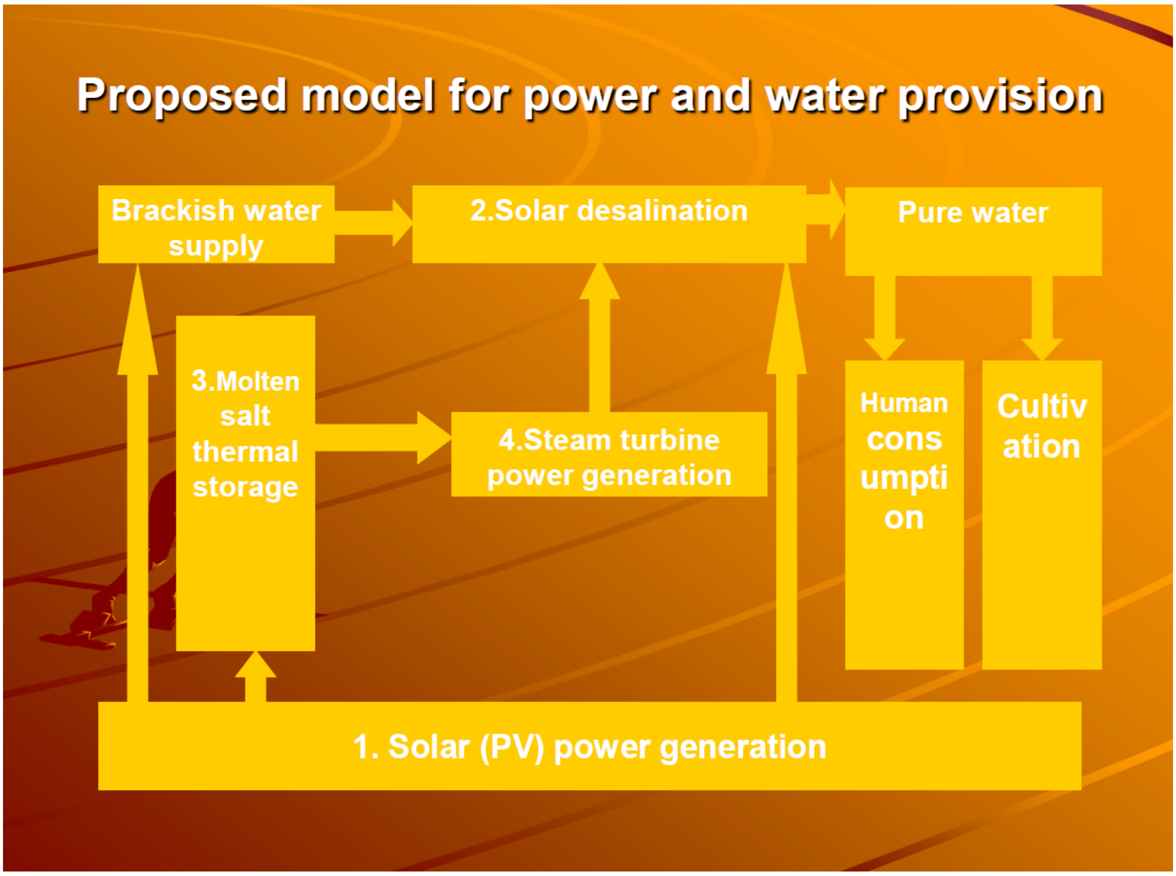
The problems

- Water shortage – available borehole water is at best brackish.
- Soil infertility (Barren land)
- Non utilization of indigenous renewable energy sources (solar energy in solar-rich countries)
- Lack of low opportunity desert land


Is their any approach to be implemented for the resolution of these problems of desert communities?
Can the subsistence needs of such communities be met by the use of renewables?


Proposed model for power and water provision
Brackish water supply
2.Solar desalination
Pure water
3.Molten salt thermal storage
4.Steam turbine power generation
Human cons umpti on
Cultiv ation
1. Solar (PV) power generation

Desert sites

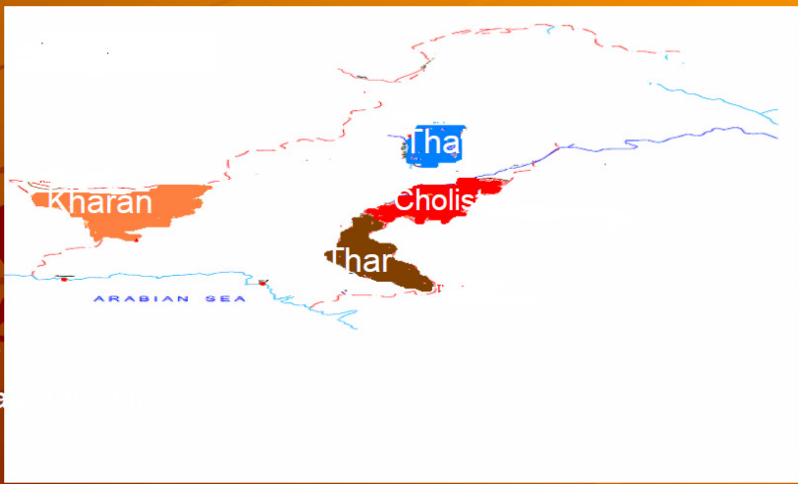


Figure 1. The location of desert sites (Kahlown, 2004)

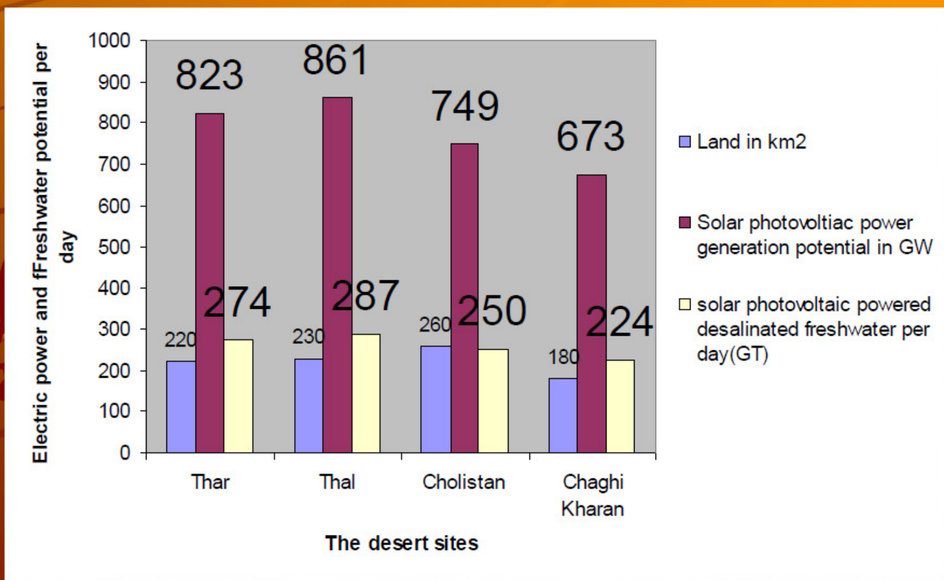
Demographic and need analysis

- Approx 15,99519 (1.59 million people) desert communities in Pakistan. The typical desert community has 500 individuals. Total population in these deserts is around 1.59 million
- Total desert communities in Pakistan are 3199
- Approximately 125 dwellings in each community. Total dwellings are 3,39000
- The energy required for the desalination and electrical power supply for each desert community is 20 GW_e (5440 kWh) per day
- The total energy for 3199 communities is around 63981 GW_e
- Difficulties in accessing to drinking water (56%) (Rosemann, 2005)
- Solar radiation is 1000 W/m² (AEDB, 2010)

Table 1.Assessment of solar photovoltaic power generation and freshwater production potential per day
(13% solar-electric efficiency-average solar day 8 hour)

Potential of desert power and energy generation per day (GW)	10% (33321)	20% (66642)	30% (99963)	40% (133284)	50% (166605)
Cholistan					
Solar PV power potential (GW)	9734	19468	29202	38936	**48670**
Thar					
Solar PV power potential (GW)	8237	16474	24711	32948	***41185***
Thal					
Solar PV power potential (GW)	8611	17222	25833	34444	**43055**
Kharan					
Solar PV power potential (GW)	6739	13478	20217	26956	**33695**

Graph 1.Electric power and freshwater potential over utilization of solar photovoltaic power generation of 1% desert land per day



Environmental benefits

Approximately 371×10^3 tonnes of CO_2 emissions based on emission factor 0.19 kg CO_2/kWh per annum could be avoided. Total savings for 3199 desert communities could rise to 1.1×10^9 tonnes CO_2 emissions/annum.

Barriers/ Issues

The approach could be implemented in all desert sites in Pakistan provided the issues of cost (life cycle) and environment degradation (sustainable environment) are addressed to prove the worth of proposed sustainable processes

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