1. Country Background

Geographically, Yemen is situated between 13N-16N latitude and 43.2-53.2 longitude at the south west of Asia. Yemen is surrounded by the Red sea from the west and by Indian Ocean (Arab sea) from the south. The country consists of three major zones: coastal, rugged foothills and Mountains. On the 22nd May, 1990 Yemen Arab Republic (YAR) and People’s Democratic Republic of Yemen (PDRY) merged to create Republic of Yemen (ROY). This unification has led to dramatic political and economical reforms in Yemen. However, since 1990 a number of occasions have led to a serious set back of the national economy. The Government of Yemen has committed economical reforms, which hopefully would lead to further economical stability and further economical recovery. Energy sector is one of the key elements of mentioned reforms.

2. Energy Profile

Oil

Oil was discovered in 1984. The total production of Yemen now has reached an average of 439,000 bpd. 50% of which is produced in Al-Masila and the other 50% is produced in the rest fields.

Gas

Natural gas finds have been made in different places. From the current confirmed estimates of gas reserves are approximately 14.173 Trillion cubic feet. Apparently, Yemen has significant deposits of gas but these reserves have not been developed or effectively utilized due to the absence of appropriate infrastructure and the inability of the government to decide on the most economic options for the gas. Now 42152 t per month of LPG are currently produced. This amount of production was reached due to participation of private sector in building bottling plants in different locations of the country and distribution of gas bottles. Actually LPG bottles are available now every where in the country. More than 80% of national market is covered.

Energy Balance

Energy consumption by sector and fuel type for the Yemen and energy balance is depicted in Figures 1 and 2. A brief analysis of the data highlights the relative importance of energy policies in the national energy regime.

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All Renewable Energy Applications in Yemen are Best Practice

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As showed by 1994 census annual statistics the fuel used in rural areas are mainly kerosene and gas for lighting. From Figure 2 one can see that these components may constitute 16% to 18% of the total consumed energy in the country. This fact means that majority of the population (rural) uses much less energy than minority (urban). Apparently, Figures 1 and 2 demonstrate that Renewable Energy Sources do not contribute to Energy Balance of the country in spite of their high potentials in Yemen.

**Power Sector**

In the power sector, Ministry of Electricity (ME) is responsible for the formulation of policies and plans for electricity development, including the control and licensing of private and industrial auto-generation. The Yemen General Electric Corporation (PEC), a semi-autonomous part of ME, is responsible for electricity generation, transmission and distribution through several grids.

PEC runs a national Grid with 132 kV transmission line of around 2150 km length and a total capacity connect to the grid is 740 MW. The power availability is around 60%.

In addition PEC runs separate isolated system in various cities which are far from the Grid with a total installed power capacity equal to 150 MW. Some of Diesel power stations are run by PEC in rural areas.

Fig 3 & 4 shows electrical energy profile in Yemen. These figures demonstrate clearly that rural consumption does not exceed 3%, which is very little. The General Authority for Rural Electricity and Water (GAREW) was responsible for electricity generation and distribution in rural areas. GAREW was established 1994 and dismantled in 2001. Since then the activities related to rural electrification were attached to PEC. Accordingly, a Department for this purpose was established. The total number of Diesel Generating Power Stations installed in rural areas has reached 119, with total capacity of 56.2 MVA. The distribution networks installed complementary to these stations, in different rural areas are 4817 km of 400V and 1866 km network of 11kV. This installation, according to GAREW, would supply around 155,780 rural households.

For the last two years ME has shown significant interest to use renewable energy source for rural electrification. This can be seen from projects and cooperation agreements done for that period.

### 3. Renewable Energy Sources (RES) Potentials

Yemen has high potentials of renewable energy sources, namely: solar, wind and geothermal. A brief description of each type will be introduced here:

#### Solar Energy

The average solar radiation in Yemen is 450-550 cal/cm²/day see Figure 5. The annual average of daily sunshine hours is between 7.3 and 9.1 hours/day [5]. An important factor, concerning solar energy application, is the perfect match of demand and potentials. For instance the availability of solar energy at winter time is very high so, daily average of sunshine hours during coldest months (October to February) is more than 8 hours per day which perfectly matches the demand for hot water. An other example is the use of PV for rural electrification. Assuming that at least 20% the rural houses are located in remote areas where it is economically justified to use PV rather than other source of electricity. The number of these houses could reach 300,000, which demonstrates the high potential of PV demand for rural
electrification reaching tens of MW. Therefore the economics of energy produced by any solar device will be higher than in another Middle East country, e.g. Syria.

**Wind Energy**

Unfortunately the available meteorological data does not contain enough information about the wind in various locations in the country.

Geographic Nature of Yemen has helped to generate daily wind with reasonable duration and speed. The well known phenomena of local wind patterns are clearly realized in Yemen. These are:

- Sea Breezes
- Mountain-valley wind

The most populated areas of Yemen are Mountain-Valley areas. There are a great number of small villages shuttered on the top of mountains where altitude is 1200m above see level or less, the electricity supply could be generated most economically by installing wind-turbine generators. The wind is available almost whole year which permits to use wind turbines in decentralized fashion to produce electrical energy for house-hold use in rural areas. In some areas the availability of sun and wind is in contrast. This situation can encourage to propose Wind-PV hybrid systems. The coastal areas high speed wind continues for more than six months that September to March. This condition is a good indicator to propose wind farms combined with Diesel generation, with PV system or connected to the grid. Further study for wind availability and daily wind speed is required to precisely assist wind generation economics.

**Geothermal Energy**

Yemen is characterized by volcanic nature. There is more than seven areas of natural hot springs of water. In addition Yemen is specified as one of the countries having high heat flow. The heat flow reflects the potential of geothermal energy. The world map of heat flow shows that Yemen and Italy have equal potential of heat flow (60 mW/cm²). The total capacity of geothermal power installed in Italy is more than 500 MW which clearly demonstrates the high potential of geothermal energy in Yemen. In 1984 a study financed by World Bank was performed by Geothermex Inc. The study was directed to investigate the availability of geothermal energy in Dhamar area (100 km south of Sana’a). The study concluded that it is possible to build a geothermal power station with a capacity of 125-250 MW. Such power for Yemen is considerably high in relation to the total installed power. Further study may be carried out in two directions:

- Further implementation of Geothermex study.
- Assessment of geothermal energy in other areas in the country.

**4. Existing Applications of Renewable Energy Technologies**

There are four types of applications namely: Photovoltaic, Solar Heaters, Wind and Biogas. The most important one is PV.

**PV Applications**

P.V. is used as a power source for different purposes:

- Telecom, TV transmission, water pumping, electrification of rural houses and some other, e.g. clinics, schools, boarding house, . . . .
- Telecommunication Transmission uses 1200 panels in different parts of the country. The total installed peak power has reached an amount of 60,400 W.
- First installation started late 80’s. Due to the successful performance and low rate of failure Telecom has expanded the use of PV as a power source to supply telecom microwave stations in the tops of the mountains.
- Television Transmission also uses in many of transmission stations located at the tops of mountains PV as a power source. The total power is 14800Wp installed in 19 stations.
- Water Pumping:

As an example of water pumping some information about Al-Mahweet Project is provided as follows:

<table>
<thead>
<tr>
<th>Finance</th>
<th>GTZ Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>PV: 600 Wp</td>
</tr>
<tr>
<td>Pump</td>
<td>70 to 100 m3/day dependant on ambient temperature</td>
</tr>
<tr>
<td>Performance</td>
<td>very good</td>
</tr>
</tbody>
</table>

- PV for Domestic Application in Rural areas

This area of application is the most promising and important one. However the installed power is not very high. The total installed peak power could not exceed 100 kWp which can be considered very little looking at number of houses using kerosene and gas for light and the great number of scattered remote houses and small villages.

Given feedback information about the performance of these systems states that most of them are functioning well.

- Ministry of Electricity project

Last year ME has succeeded to include in the Government yearly budget a special fund to initiate a rural electrification project based on PV technologies. A tender was announced and the procurement process has reached final stage. The project constitutes supply, deliver, install, test
and commission PV and wind turbine systems for rural electrification of a village in Abyan Region. The PV and wind turbine systems details are given in the Table below:

<table>
<thead>
<tr>
<th>No</th>
<th>System Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PV, NAPS 50Wp, 12V, NR50G Module</td>
<td>75</td>
</tr>
<tr>
<td>2</td>
<td>PV, NAPS 75Wp, 12V, NR75G Module</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Wind Generator, 500W</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>PV Water Pump system, 43Wp, 48V</td>
<td>10</td>
</tr>
</tbody>
</table>

In order to achieve sustainability and successful implementation ME decided an implementation procedure. This procedure is based on agreements between ME and end-users and local authority. The agreements outline rights and obligations of all parties involved, including the obligation of end-user to pay for this service within the average of rural house hold electricity consumption for seven years (YER5000 as down payment and YER500 per month). The revenue shall be used for monitoring, maintenance and expansion. The fund from the Government is included in the budget of year 2003 and hopefully the fund shall continue for future too. Due to the success achieved last year new project was procured this year. The project consists of 70 PV systems for rural electrification. Each system consists of two PV panels, having 40 Wp each in addition to the battery and other accessories.

Schools and Medical Clinics:

For the last five years a number of schools and medical clinics built in remote areas were electrified by means of PV systems. The total peak power is around 20kW.

Solar Heaters

A private company was recently established, called "Solar Heaters Manufacturing Company Ltd." It is registered in Sana’a, Republic of Yemen. The Company produces solar heaters locally. Technology, equipment and machinery were imported from China, Ninesung Co. Accordingly, a factory installation has been finalized this year. The production now is 500 units per month with possible increase up to 750 per month to meet increasing demand of the market. Each unit consists of two solar collectors having an area of two m² each, water tank of 100 letter capacity, piping and other accessories, e.g. measuring instrument and back up electrical heating element. In addition the factory produces smaller unit with collector having an area of one m² each, water tank of 100 letter and the accessories. Although the business is newly born marketing is going on significantly successful due to the following reasons :

- Perfect match of demand and production. The daily average of sunshine hours during coldest months (October to February) is more than 8 hours per day.
- Differential Tariff Schedule of electricity, so that heating by electricity is now more expensive than by solar heater.

PEC has an interest to diffuse this industry because the use of solar heaters shall result in electricity losses reduction and shall reduce electricity daily cut-off.

PEC has sufficient institutional set up, capacity building and technical ability to be an implementing entity for such project.

Direct environmental effect of the project so that diffusion solar heaters shall lead to less burning of conventional fuel.

The end user prices are: US$270 for small unit and US$480 for large unit.

Biogas Technology

Biogas project was established in Al-Habeel (Mansorah village) Lahj governorate in 1990’s by the Ministry of Electricity and the assistance of ESCWA organization, the project was financed by UNIFEN and the government of Holland. The project consists of:

- 22 digesters (family size).
- 10 Animal sheds connected to digester.
- 22 W.C. connected to digesters to solve the problem of sanitation in the village which was so serious problem due to its impact on the environment (ground water pollution, indoor pollution).

The outcomes of the project was as follows:

- Providing the beneficiaries with clean, low cost energy for cooking.
- Providing the beneficiaries with a pure natural fertilizer.
- Solving the problem of sanitary disposal of village wastes.
- Protecting the inhabitants from the disease caused by wastes, smoker of wood burning, . . . etc.
- Preventing of further desertification caused by wood cutting.

Apparently, it is very useful to disseminate biogas technology to other similar rural areas due to mentioned above advantages.

Wind

Although the potentials are high the applications in this area are ignorant. However one can mention the following projects:

- In Al-Mukha Power Station there is an experimental Wind turbine installed by PEC.
- As mentioned earlier German Government is going to finance a Feasibility Study to build a wind farm to produce electricity.
- TV corporation has use wind turbine in combination with PV panels as electricity generating source for TV transmission stations.


Although many factors should encourage to use of RES technologies, e.g.
high potentials of renewable energy sources in Yemen

Lack Specialized Financing Agencies: In this work it is proposed to establish a specialized financial agency similar to Agricultural Credit Bank. However, such agency should have more sophisticated procedure and functions due to the special role.

Lack of Coordination: The coordination between different stakeholders and concerned parties is as important as the institutional framework. Therefore, it is necessary to develop an efficient mechanism for coordination.

Lack of Institutional Framework: This is the most important constraint because the absence of adequate institutional framework has led to the failure of most trials and pilot projects aiming to disseminate PV technologies in rural electrification. Therefore, it is vital to establish a consolidated institutional framework. The institutional framework is in fact the efficient tool to achieve the goals and objectives. Subsequently, the institutional framework should be based on clear objectives and policies encouraging the use of PV technology rather than Diesel Generating Sets.

Lack of Private Sector Participation: Unfortunately there are a number of problems faces private sector participation, e.g. (a) only two manufacturers are represented in Yemen, namely Siemens and Solarix; (b) consequently the competition is almost absent hence average price for RES technology is very high (recent tender the cheapest prices were: for PV system $11.5/Wp, for wind $4.75/W, etc., (c) capacity building is weak.

Lack of Legal Framework: The establishment of a legal framework is an important component of the subject in order to regulate the relations and functions of different stakeholders. Therefore, a clear legislation framework is necessary to be developed.

Lack of Public awareness: It is proposed to initiate a governmental program aiming for public awareness about renewable energy sources technologies and their advantages and benefits.

6. International and Regional Cooperation

Due to the high availability of RES and high potential of market many international and regional agencies have initiated cooperation projects with Yemen government. These are ESCWA, UNDP, World Bank, GTZ, Dutch Government, European Union, Jordanian Government, Japan and Egypt. It is worth to mention that there is a lack of coordination either inside Yemen or between Yemen these agencies / between these agencies themselves. For example UNDP project intends to develop a viable business model to launch and sustain market development for pertinent PV applications. The project aims also at overcoming the financial barriers house-
holds face in rural areas to access renewable energy systems. Other International Organizations’ (World Bank, GTZ, Dutch Government) projects aim at developing rural electrification strategy. Japan Project consists in emission reduction. Consequently, more applications of RES technologies are included. Further information about the subject can be found in [7,8,9,10].

7. Conclusions

This Paper has provided a brief introduction to the Country background. Further the Country Energy Profile was introduced, energy used and energy services in rural areas, showing energy consumption in different sectors, eg. transport, electricity, .. et. In addition basic information about electricity production, consumption and consumer categories was provided. In order to demonstrate the potentials of Renewable Energy Sources in Yemen, namely: solar, wind, geothermal, a brief introduction was given. Further more the existing applications and gained experience of renewable energy technologies were briefly presented. The application of PV technologies in Telecom and TV repeating stations has proven good success and high reliability. However it is necessary to encourage wider use of PV technologies in rural electrification due to high market potential as shown by this Paper. The newly burn solar heater industry has quickly achieved considerable success due to reasons mentioned above and particularly the perfect match between the demand for the hot water and the availability of solar energy during winter time. The Biogas project experience has demonstrated many advantages and benefits of using such simple and cheap technology. This fact should encourage disseminating biogas technology to similar areas. Due to the fact that the applications do not match the potentials the Paper has discuss barriers to disseminate RES technologies in Yemen, eg: Market, Institutional, Technical, Economical and financial, Social and other barriers and how they could be overcome. Here one can conclude that unless the Institutional set up is firmly built other barriers would not perhaps be possible to overcome. Actually, International Agencies and Organizations are interested to help the use and diffusion of RES technologies. Therefore the Paper has mentioned international and regional cooperation in Yemen. This has cover ESCWA, UNDP, UNDO, World Bank, Germany, Dutch Government and Japan.

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