Geothermal energy development and future possible applications in Algeria

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***Abstract*— The main objective of the present study is to review the development of geothermal energy utilization in Algeria, giving its historical development and opportunities. Geothermal energy is used for direct utilization in Algeria, which is among the main countries in Africa in geothermal direct use applications. The inventory of thermal springs has been updated with more than 240 springs identified. The highest temperatures recorded were 98 °C in Hammam El Maskhoutin (Guelma) and 118 °C in Biskra, in the western part of the country. In the south, the thermal springs have a mean temperature of 50 °C. The northeastern zone of the country, covering an area of 15,000 km2, remains potentially the most interesting geothermal area, with the Barda spring giving 100 L/s. Geothermal energy is a relatively benign energy source, displaying fossil fuels and thus reducing greenhouse gas emissions. So it is expected that geothermal energy development will significantly speed up in the country if the geothermal law becomes effective.**

Keywords*— Geothermal energy; Direct use; Heat pumps; Space heating; District heating; Renewable energy; Sustainable development.

I. Introduction

There is a general consensus within the global scientific community that climate change is occurring as a result of greenhouse gasses, such as carbon dioxide, being emitted into the atmosphere. The emission of greenhouse gasses can be largely attributed to energy generation through the burning of fossil fuels, such as; coal, natural gas and oil [1].

Algeria commitment to the environment, energy security and climate change mitigation under the Paris Agreement has proven in all levels of government communicate the utmost importance of utilizing more renewable and sustainable energy resources available as an alternative solution to reduce the dependency on finite fossil fuel reserves. Algeria participates in many renewable energy programs such as the Mediterranean program for renewable energy (MEDREP) whose two main objectives are: to provide sustainable energy services particularly to rural populations and to contribute to the mitigation of climate change by increasing the presence of RE of all the energies in the region. This program is realized by the Mediterranean Center for RE (MEDREC) in Tunisia [2].

Geothermal energy is classified as one of the important renewable energies, which is environmentally friendly, green, reliable and sustainable energy, it is literally the heat contained within the earth that generates geological phenomena on a planetary scale. Geothermal energy is often used nowadays, however, to indicate that part of the earth's heat that can, or could, be recovered and exploited by humankind in many applications such as electricity generation, space heating/cooling, aquaculture pond, bathing and swimming and others, The potential of geothermal energy can be harnessed through a number of techniques, all of which attempt to utilize the thermal energy stored within the earth [1].

Based on the 2015 World Geothermal Congress report, the estimation of the installed thermal power for geothermal direct utilization in a total of 82 countries up to the end of 2014 equals 70,885 MWt, with growth of 7.9% annually compared to 2010 data, however the total annual energy use is 592,638 TJ and more than the half of the world wide thermal energy is used for the ground source heat pumps. Energy savings amounted to 352 million barrels, preventing 46.1 million tonnes of carbon and 149.1 million tonnes of CO2 being released to the atmosphere [3].

Since 1967 the geothermal resources exploration started in Algeria. Thus far, more than 240 thermal springs have been recorded in the country with the highest temperatures recorded were 98 °C in Hammam El Maskhoutin (Guelma) and 118 °C in Biskra, in the western part of the country. Algeria is the leader of the direct utilization of geothermal energy in Africa as illustrated in Table 1 with 54.64 MWt installed thermal power and annual energy use of 1699.65 TJ/year, indeed the distribution of geothermal direct use by country in Africa indicated that more than 39% of the installed thermal capacity is located in Algeria, furthermore for space cooling (air conditioning) application, Algeria ranked as the fifth country in the worldwide. The main utilization of the geothermal energy in Algeria are balneology which represent almost 82% (44.37 MWt) from the total geothermal power utilization (54.64MWt), therefore just 18% (10.28MWt) utilized for other applications such as space heating, heat pumps and fish farming as shown in Fig. 1 [3, 4].

As per the renewable energies and energy efficiency program have been launched by the Ministry of Energy, Algeria aims to growth the geothermal energy utilization in the first phase 2015-2020 by 5 MWt and in the second phase 2021-2030 by 10 MWt to achieve additional 15 MWt by 2030, this intention will be executed by the implementation of many projects such as the binary-cycle geothermal power plant planned in Guelma, Tilapia fish farming in Ghardaia, Tamanrasset and Ouargla prefectures and heat pump installation in several locations [5, 6]. This paper outlines the geothermal energy development in Algeria, current status and the future promotion and prospective, thus the different applications have been discussed in details.

TABLE I. DIRECT UTILIZATION OF GEOTHERMAL ENERGY IN AFRICA [3]

Country	**MWt**	**TJ/year**
Algeria	54.64	1699.65
Egypt	6.80	88.00
Ethiopia	2.20	41.60
Kenya	22.40	182.62
Madagascar	2.81	75.59
Morocco	5.00	50.00
South Africa	2.30	37.00
Tunisia	43.80	364.00
Total	140	2,538

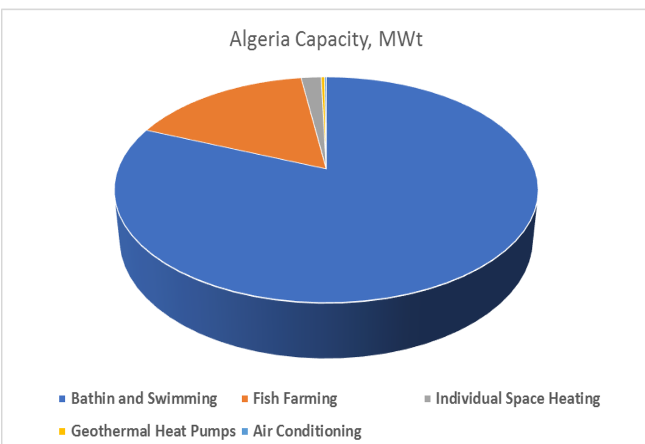

Fig. 1. Algeria geothermal direct applications in 2015 [3].

II. GEOGRAPHIC LOCATION OF ALGERIA

Algeria is an African and a Mediterranean country situated in the center of North Africa between 38 and 351° latitude north and 8–121° longitude east and has a spread over an area of 2,381,741 Km2 and became the largest in Africa since South Sudan independent from Sudan in 2011. Algeria is bordered by the Mediterranean Sea in the north, Tunisia and Libya toward the east, Mauritania, Niger and Mali in the south, and Morocco in the west (Fig. 2). The country's population currently stands at 38.8 million inhabitants; over 90% of this population is spread over 10% of the national territory [2, 6].

The climate is very different between regions (North-South, East-West). The Mediterranean is across the northern fringe encompassing the coast and the Tell Atlas which is present in the temperate zone and enjoys a mild, temperatures in summer average between 21 and 42 °C (70 and 108 °F) and in winter drop to 10 to 12 °C (50 to 54 °F). Winters are not cold, but the humidity is high and houses are seldom adequately heated. In eastern Algeria, the average temperatures are somewhat lower, and on the steppes of the high Plateaus winter temperatures hover only a few degrees above freezing. In the Sahara Desert (South of Algeria) even in winter, midday desert temperatures can be very hot. After sunset, however, the clear, dry air permits rapid loss of heat, and the nights are cool to chilly. Enormous daily ranges in temperature are recorded with extreme highs of 49 °C (120° F) [7, 8].

Rainfall is fairly abundant along the coastal part of the Tell, ranging from 400 to 670 mm (15.7 to 26.4 in) annually, the amount of precipitation increasing from west to east. Precipitation is heaviest in the northern part of eastern Algeria, where it reaches as much as 1,000 mm (39.4 in) in some years. Farther inland the rainfall is less plentiful. Prevailing winds that are easterly and north easterly in summer change to westerly and northerly in winter and carry with them a general increase in precipitation from September to December, a decrease in the late winter and spring months, and a near absence of rainfall during the summer months [7].

Energy resources in Algeria are numerous, in which has the 16th largest oil reserves in the world and the second largest in Africa, while it has the 9th largest reserves of natural gas in the world. It has been an OPEC member since 1969 and its crude oil production stands at around 1.1 million barrels/day. Oil and gas export revenues account for more than 95% of Algeria's total export revenues, around 60% of budget revenues, and 30% of gross domestic product (GDP).Algeria's geographic location has several advantages for extensive use for most of the renewable energies and signifies that it is in a well position to play an important strategic role in the implementation of renewable energy technology in the north Africa, as well as providing sufficient energy for its own needs and even exporting such projects to other countries of Europe [9,10].

Fig. 2. Geographic location map of Algeria [11].

III. Literature Review on Geothermal Energy Development in Algeria

Thermal springs have been used for bathing, washing, and cooking purposes by humankind since thousands of years. At the beginning of this century, many experiments and projects have been undertaken in many countries to use the geothermal energy resources for many applications such as production of electricity, direct use of heat, geothermal heat pumps, etc [12, 13].

As for a brief history of geothermal energy development in Algeria; before the 1962, geothermal resources were only used spontaneously for bathing and swimming in the ancient Roman pools and primitive shelters. The exploration program started in 1967 and was undertaken by SONATRACH (National Company of Hydrocarbons, Research, Production, Transport, Transformation and Marketing). In 1982 the national electric power company SONALGAZ (sector from SOATRACH) undertook the geothermal identification studies of the northern and eastern parts of the country in association with the Italian company ENEL. From 1983 onwards the geothermal activity has been continued by the Renewable Energies Center of Algeria (CDER) and the program was extended to the whole northern part of the country [14].

In 1988 Fekraoui et al published a paper in which they stated some studies and projects have been undertaken for the preliminary geochemical exploration between 1967 and 1969, geophysical prospection in the north-east of Algeria and some gradient boreholes were drilled in Guelma, Sidi Zid area between 1978 and geothermal exploration study of the Constantinois Oriental area have been conducted between 1980 and 1982. As result of this a map of geothermal resources in Algeria has been prepared and an inventory of hot springs has counted more than 200 geothermal sources in the country [15].

In 1995 world geothermal congress and based on Fekraoui et al and Bellache et al papers (1995), it has reported that the inventory of thermal springs has been updated with more than 240 identified hot springs and some greenhouses at Ouargla and Touggourt in the central region are using 60°C Albian geothermal water for heating, thus the energy utilization estimated to be 1657 TJ/yr and a thermal power of about 100 MWt [16, 17, 18].

Since 1996, apart from some studies investigated the chemical characteristics and the estimated underground temperature in some hot springs such as Kedaid et al (1996) and Lahlou Mimi et al (1998) there are no papers published for the geothermal energy data in Algeria up to the world geothermal congress held in 2005. Even Lun et al (2001) reported in the world geothermal congress the same energy utilization and thermal power indicated by Freeston et al in 1995 [19-20].

Fekraoui and Kedaid reported for the world geothermal congress held in 2005 that an investigation have been carried out through the recorded 240 hot springs in the north and the Albian water wells in the south of the country and all identified as low enthalpy resources with the maximum reservoir temperature, is 120°C. The total installed capacity of 152.3 MWt up to the end of 2004 and the main utilization is bathing and balneology for around 98% and 2% for greenhouse and space heating; however Lund et al 2005 have estimated the total energy use is 2,417 TJ/year. Note that the total installed capacity of 152.3 MWt looks an unrealistic capacity compared to the total installed capacity reported in the world geothermal congress 2000 and 2010 are respectively 100 MWt and 66.84 MWt, however on double check of Fekraoui and Kedaid paper the table 1 gives a total installed capacity for the country of 63.3 MWt [19, 21,22].

Lund et al indicated in the 2010 world geothermal congress report that the total thermal power of 66.84 MWt and energy use of 2098.68 TJ/yr in Algeria in which more than 82% of the total thermal power used for balneotherapy in the hot springs located mainly in the northern part of the country, and the rest 18% utilized for fish farms in Ghardaia and Ouargla sites using the Albian geothermal water of the Sahara region to produce about 1500 tonnes/yr of Tilapia fish and Ain Skhouna site, located near Saida produced 200 tonnes of Tilapia during 2008, additional to a small geothermal heat pump project has been developed in the Saida region for heating and cooling 12 classrooms in a primary school and some individual space heating [13, 19, 23-25].

In the world geothermal congress 2015, Saibi has reported that the inventory of thermal springs has been updated with more than 240 springs identified. The highest temperatures recorded were 68°C for the western area, 80°C for the central area, and 98°C for the eastern area. In the south, the thermal springs have a mean temperature of 50°C. Hence Lund et al 2015 indicated that a total installed thermal power for the country equals 54.64 MWt and thermal energy used is 1699.65 TJ/year. Bathing and swimming is the dominated application with more than 82% from the total thermal power utilization, therefore 18% divided into the other applications, space heating, fish farming, air conditioning and heat pumps [3, 4, 26].

Based on the points cited above and as illustrated in Fig. 3, despite the large potential and the several resources available in the country geothermal energy development remained almost stagnant over the past two decades in Algeria. As the country being a major producer and exporter of oil and natural gas, authorities did not pay more attention on the geothermal energy development. Even with the increasing in importance of the climate change commitment and sustainable development, geothermal energy still not on top of the renewable energies development in the country. According to the renewable energies and energy efficiency program have been launched by the Ministry of Energy in 2016 government intended to growth geothermal energy just by 15 MWt within 2030, since the intended total power capacity is mainly divided between solar and wind energy [5].

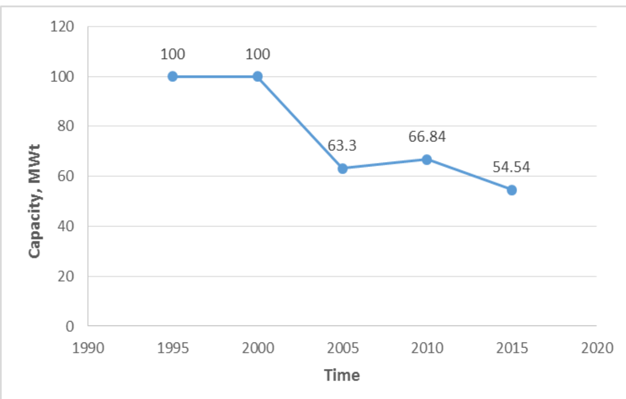

Fig. 3. Installed direct-use geothermal capacity in Algeria from 1995 to 2015 [3, 16, 19, 27, 28].

IV. Geothermal Resources in ALGERIA

The inventory of the thermal springs has been updated to show more than 240 sites. The temperatures of Algerian hot waters vary from 22 to 98 °C. The highest spring temperatures recorded are: 68 °C for the western area (Hammam Bouhnifia), 80 8C for the central area (Hammam El Biban) and 98 °C for the eastern area (Hammam Meskhoutine) in northern Algeria (Fig. 4). In the southern area, there are some thermal springs with a mean temperature of 50 °C. The total dissolved solids (TDS) of the hot springs in northern Algeria are greater than 1 g/L (Fig. 5). Carbonate formations constitute the main geothermal reservoirs in northern Algeria, while in southern Algeria the reservoirs are dominantly composed of sandstone. Three geothermal regions have been delineated according to the distribution of thermal springs and geological and geophysical considerations (such as permeability and geothermal gradient) [14, 25].

A. The Tlemcenian dolomites in the northwestern area

According to the chemical types of the waters, this north western area can be divided into two zones: a southern zone is characterized by homogenous geological formations (dolomites and carbonates) and dominantly Ca–HCO3-rich waters. The northern zone is set on allochthonous terrains. The thermal springs have a variety of chemical types. The studies of the former zone gave little information about the reservoir and the thermal water origin. Verdeil and Blavoux and Collignon have established a close relationship between the thermal springs and the seismicity of the area. The isotopic data, particularly 13C and 18O, show that the waters are of a deep origin. Fenet indicated that the main thermal springs originated from deep transverse faults. The Plio-Quaternary volcanic rocks in the coastal zone could be related to the thermal waters such as at Hammam Bouhadjar and Hammam Bouhnifia. To the South of this zone, the Jurassic dolomites of Tlemcen on the Tlemcen-Saida axis constitute a shallow reservoir. About fifteen thermal springs whose temperatures range from 25 to 47 °C have been recorded as bicarbonate water type [4, 14].

B. Carbonate formations in the northeastern area

This area covers approximately 15,000 km2 and consists of mainly carbonate formations. In the northeastern part of Algeria, the Neritique Constantinois formations and the carbonate part of the Tellian sheet form the reservoirs of Guelma and Bouhadjar, respectively. This area is characterized by springs of high flow rates, i.e. more than 100 L/s for Hammam Barda and by the highest temperature in the country (98 °C for Hammam Maskhoutine, see Fig. 6). The thermal waters in this area are chemically dominated by chloride and sulphate, and have TDS ranging between 1.6 and 2.2 g/L. Two prospects have been chosen for more detailed investigations where geothermal reservoirs could exist at different depths. On the basis of 18O and 2H analyses performed on waters from the northeastern areas, the thermal waters are of meteoric origin [14, 23].

C. Albian sandstone reservoir in the Sahara area

Thermal springs are scarce in this area. The Albian aquifer is exploited by the wells mainly for domestic and agricultural purposes. The sandstone Continental Intercalary formation constitutes the reservoir for the Albian aquifer, covering an area of 600,000 km2. This reservoir outcrops in its southern part and dips towards the north to reach a depth of 2600 m in the Biskra region. This reservoir is covered by calcareous formations which yield the chemical characteristics of the water type (CaNa–SO4Cl) with a mean TDS of 1.5 g/L [14, 24].

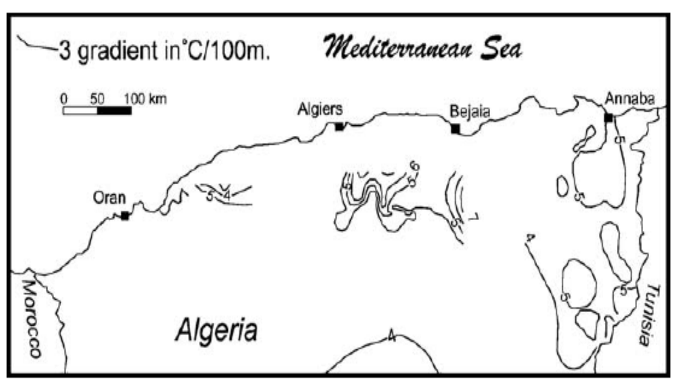

Fig. 4. Geothermal gradient in the northern part of Algeria [14].

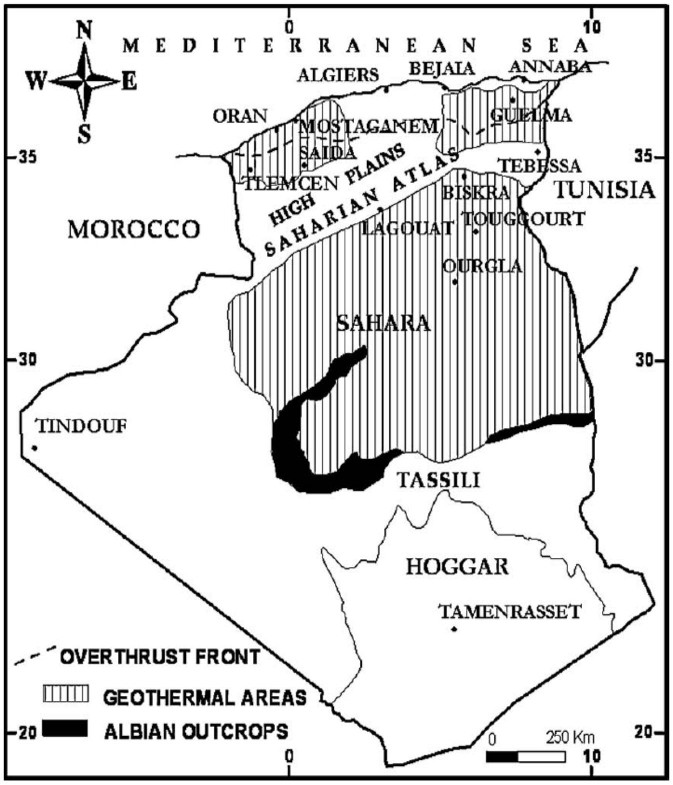

Fig. 5. Main geothermal areas [14].

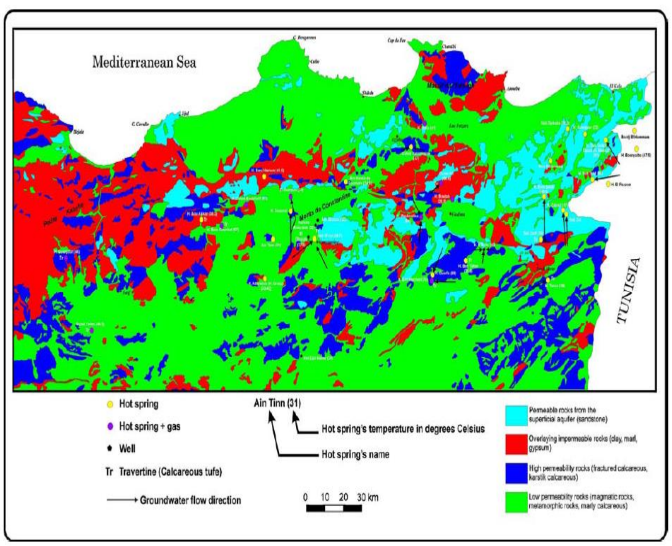

Fig. 6. Hydrogeologic map of the northeastern part of Algeria showing the location of the hot springs with their surface temperatures and the direction of the groundwater flow [14].

V. GEOTHERMAL ENERGY UTILIZATION IN ALGERIA

The main utilizations of the hot water in Algeria are balneology and space and greenhouse heating. Recently, some new projects are established for fish farming and agriculture, where the Algerian government gives financial support of 80% for such projects. A heat-pump project was installed in Saida area for heating and cooling purposes. A thermal water of 46 °C with a flow rate of 25 m3/h was used for this project [4, 14].

A similar project is planned in Khenchla area and a binary-cycle geothermal power plant is also planned in Guelma area. Recently some Tilapia fish farming projects started in Algeria (Ghardaia, Tamanrasset and Ouargla prefectures). These projects utilize the hot waters of the Albian aquifer of south Algeria. For practical reasons, the Ouargla and Touggourt sites (north-eastern of the Algerian Sahara Fig. 7) have been chosen for the experimental greenhouses / geothermal heating systems. These greenhouses are used for melon and tomato cultivation. Even though the Sahara area is characterized by hot weather, important temperature variations are recorded during the winter, and the summer seasons where the night temperatures could reach a value below 0 °C. Eighteen greenhouses covering a total surface of 7,200 m2 are heated by the 57 °C Albian geothermal water [14, 24].

The source temperature combined to a flow rate of 1 L/s is used to assure a minimum temperature of 12 °C inside every greenhouse. The heating system, which is a reserve flow type, has been operating since 1992. The polypropylene tubes are put directly on the ground close to the plants. The main results are precocity of 20 days and an increase of 50% in production, compared to that of the unheated greenhouses. Bellache et al, (1995) states that the geothermal potential in these regions is sufficient to heat 9,000 greenhouses, with a flow of 3,421 L/s. The total energy use for geothermal is about 1,778.65 TJ/yr[14, 17].

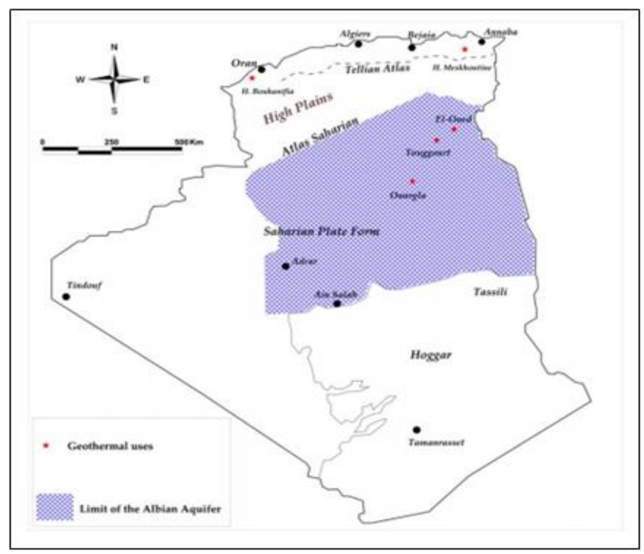

Fig. 7 Location of Algerian geothermal uses sites [4]

VI. GEOTHERMAL ENERGY UTILIZATION OPPORTUNITIES AND PROSPECTS IN ALGERIA

To date, all geothermal district heating investments have been carried out by the governorship and municipalities. However, the private sector has expected to realize these investments as investors with the governorship and municipalities, under Algeria conditions. All necessary infrastructures are being set up to develop rural regions. Supplying natural gas to some regions (especially in the mountains) is, very difficult, and the use of renewable energies (solar and geothermal) could be of great benefit and provide an alternative solution [4, 24].

Renewable energies and energy efficiency program have been launched by the Ministry of Energy, Algeria aims to growth the geothermal energy utilization in the first phase 2015-2020 by 5 MWt and in the second phase 2021-2030 by 10 MWt to achieve additional 15 MWt by 2030, this intention will be executed by the implementation of many projects such as the binary-cycle geothermal power plant planned in Guelma, Tilapia fish farming in Ghardaia, Tamanrasset and Ouargla prefectures and heat pump installation in several locations [2, 10].

Even only low-enthalpy geothermal resources are available in Algeria . Geothermic is not excluded from the electric option of the renewable energies network. Some of these sources can be exploited for the purpose of renewable electricity production. This point of view is strengthened by the presence of a fairly large number of hot springs in different parts of the country. More than 200 geothermal sources were counted by the CDER and are recorded, in which one-third's temperatures are increased to 45 C and where the highest temperatures registered are 98 C in Hammam El Maskhoutin (Guelma), in the western part of the country. These hot springs are numerous but unfortunately not industrially exploited [2].

This large potential can be used for various geothermal energy applications such as greenhouse heating, balneology, thermal tourism, heat pumps, aquaculture pond and raceway heating, space heating, industrial process heat, snow melting and space cooling and other uses. However, in order to exploit this geothermal resources privatization and restructuring studies have started in this sector and the required legislation for private sector and foreign investment are arranged, therefore new financing mechanisms are also needed to promote investment in renewable energy efficiency and geothermal energy [14, 29].

VII. Conclusion

Geothermal energy is a clean, proven, and reliable resource for supplying the needs of a sustainable society and helping to improve the global environment. The Algerian government has adopted new renewable energy laws and financial support for the investors to facilitate the exploitation of the renewable energies for electricity production and direct utilizations. Algeria has relatively abundant geothermal resources especially in the northeastern parts but not totally used.

Despite the determination of the three main geothermal areas, more detailed geophysical, hydrochemical and geothermal reservoir engineering studies are needed to delineate the reservoirs and to evaluate their energy potentials. The main conclusions derived from the present study may be summarized as follows:

- Geothermal energy offers technically and economically feasible possibilities for the development of different agricultural production sectors in Algeria.
- Up-to-date information on geothermal energy utilization in Algeria could not be easily and completely found. There were some differences between the data given by various researchers. This means that, in general, good documented systems for geothermal energy should be established in the country.
- It should be underlined that is already confirmed and proven that geothermal energy can be commercially competitive with other energy sources.
- Industrial applications of geothermal energy are few in number in Algeria.
- One of the most important barriers preventing widespread use of renewables is the lack of a coherent national energy plan in which the role of renewables is well explained, as well as defining properties among alternatives.
- In the long term, geothermal energy will remain a viable option to furnish clean, reliable power in Algeria.
- Geothermal development offers a viable energy alternative to fossil fuel. However, environmental and social dimensions of geothermal development must be carefully and properly managed.

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