Chapter 5
Energy Resources in Northern Africa

5.1 Introductory Remarks

Traditionally, the countries that are referred to as North Africa are Egypt, Libya, Tunisia, Algeria, Morocco and Western Sahara. These are the Arab States in the African continent but a country like Sudan which has had long history of association with North Africa is often included as part of the region.

The region is bordered by the Red Sea to the East, the Atlantic Ocean to the West, the Mediterranean Sea to the north and the Sahel to the south and covers an area of 8,935,660 km^2 (including Sudan). Its coastline along the three water bodies namely the Red Sea, the Mediterranean Sea and the Atlantic Ocean, covers a distance of about 10,016 km, which represents about 29 % of the African coastline. Three important features of the region are its long coastline, the Sahara desert and the mountain ranges (the Atlas Chain and the Rif Mountain). A further classification refers to Western Sahara, Morocco, Algeria, Tunisia and Libya as the Maghreb region while Egypt and Sudan as the Nile Valley region. Mauritania and South Sudan, which are also close to these regions are not considered to be part of North Africa. However, it is more convenient to discuss Sudan (North and South) as one entity while Mauritania is covered under Western Africa. Most territories of Northern African states are covered by sandy and rocky desert and are not suitable for agriculture. For example, in Libya, only 2 % of the total land area is arable. Egypt and Sudan, on the other hand, have comparatively larger arable land particularly along the River Nile basin, which stretches from East Africa through Sudan and Egypt into the Mediterranean Sea. These characteristics determine the population distribution in the region. Therefore most of the population lives in areas where the climate is hospitable and where most of the economic infrastructures and services are located. Such areas are the coastal regions, the mountainous region of the Tell in the Maghreb and the Nile Valley in Egypt and Sudan. Despite these widespread hardships, the population of the entire region has been able to double within the last three decades.

H. Othieno and J. Awange, *Energy Resources in Africa*,
DOI 10.1007/978-3-319-25187-5_5

First, energy potentials and applications are discussed in general for Northern Africa region. This is followed by brief focus on individual Northern African countries with emphasis on hydrocarbon fuels (oil and natural gas) and levels of electricity generation. For energy analysis purposes, Eritrea and Ethiopia are given attention at the end of this chapter.

5.2 Conventional Energy Resources in North Africa

As was pointed out in Chap. 1, Northern Africa is endowed with hydrocarbon energy resources such as oil and natural gas, which are in abundance mainly in Algeria, Libya and, to some extent, in Egypt. There were also significant oil reserves in Sudan while it was a unified one country but, since the secession of southern Sudan, the reserves in Northern Sudan were reduced to about one third. Southern Sudan is now more associated with East Africa than with North Africa. There is also limited amount of coal reserves in Morocco, Algeria and Egypt, which have not been extensively exploited. Similarly other available hydrocarbon resources that have not been exploited are shale oil and gas.

Unlike hydrocarbons, renewable energy resources are fairly well distributed over the whole region. Unfortunately, they are still underexploited, but there are on-going plans to increase their contribution to the overall energy provision in the region. Some of these are discussed in this chapter.

5.2.1 Oil

North Africa, for a long time has dominated oil production in Africa. The region has total oil reserves of about 70.5 billion barrels. In 1990, it contributed 65 % of the total oil reserves in Africa but this has since gone down to about 56 % due to the new discoveries of oil in other parts of Africa, such as Angola, Uganda, Kenya and the Democratic Republic of Congo (DRC).

Indeed, as shown in Fig. 5.1, oil reserves in North Africa have continued to increase by about 75 % during the last two decades. Figure 5.2 shows the proven oil reserves for North African countries for the year 1990, 2000 and 2013. Libya has the highest proved oil reserves in the region. Its 2014 estimated reserve of about 48.47 billion barrels represented 68.8 % of the total oil in North Africa. It is believed that Libya still has a huge unexplored offshore oil reserves but, currently, its most important reserves are located in the Sirte Basin.

It can be seen that there has been a general increase in the proven reserves for the region. Algeria has the second largest oil reserves in Northern Africa and is the third in Africa after Libya and Nigeria. It has however been reported that the full oil potential in Algeria has not been fully established. The fields with substantial oil reserves are situated mainly in eastern Algeria, with the fields at Hassi-Messaoud

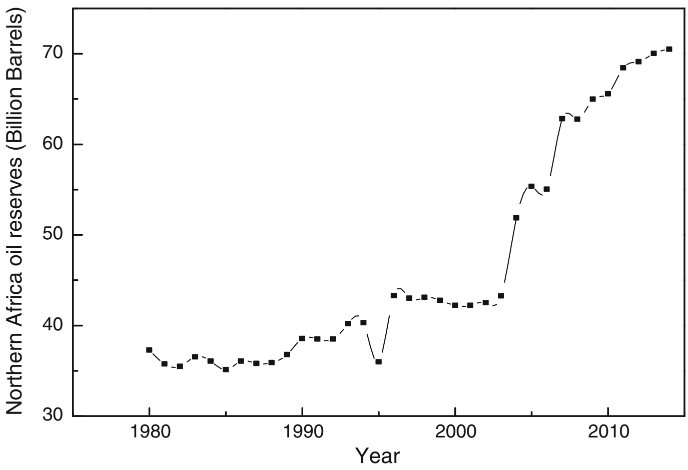
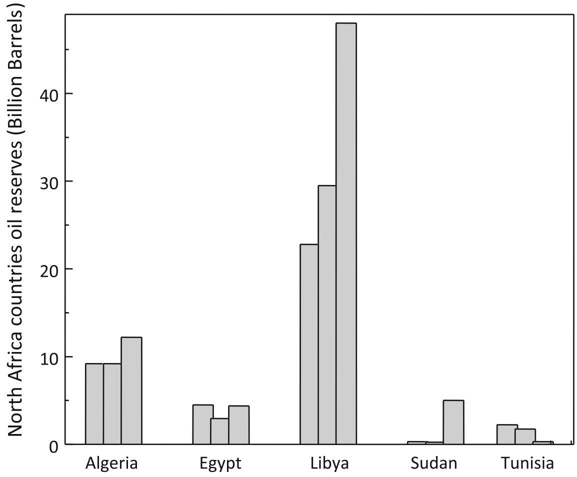


Fig. 5.1 Proven oil reserves in North Africa since 1980

Fig. 5.2 Proven oil reserves in 1990, 2000 and 2013 for five Northern African countries



holding more than 70 % of all the Algerian reserves. The other oil fields are located in the Illizi, the Rhourde Nouss, Ghadames and the Oued Mya basins. In Egypt, oil reserves are located in the Western Desert, the Gulf of Suez and the Sinai Peninsula.

5.2.2 Natural Gas

In addition to oil, North Africa also has a huge natural gas proven reserve and is leading in natural gas production in Africa. Using the EIA data [3], proved natural gas reserves in Northern Africa was estimated at 8.39 trillion m^3 in 2013. This represented more than 57 % of the total proven natural gas reserves in African. Figure 5.3 shows the growth of the proven natural gas reserves for Northern Africa since 1990.

Figure 5.4 shows the proven natural gas reserves for individual Northern Africa countries for the years 1990, 2000 and 2013. There has been a continuous increase in the amount of proven natural gas reserves for the region. The most important increase is that of the Egyptian natural gas reserves which more than doubled in the same period. The Egyptian natural gas fields are located mainly in the north of The Western Desert, the Mediterranean coast, and the Nile Delta. However, Algeria had the largest proved reserves in Northern Africa, the second largest in Africa and the

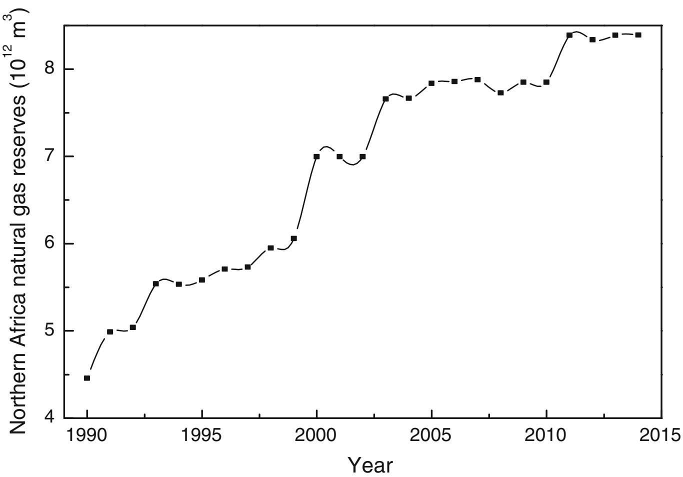


Fig. 5.3 Proven natural gas reserves in North Africa since 1990

Fig. 5.4 Proven natural gas reserves from 1990, 2000 and 2013 for six Northern African countries

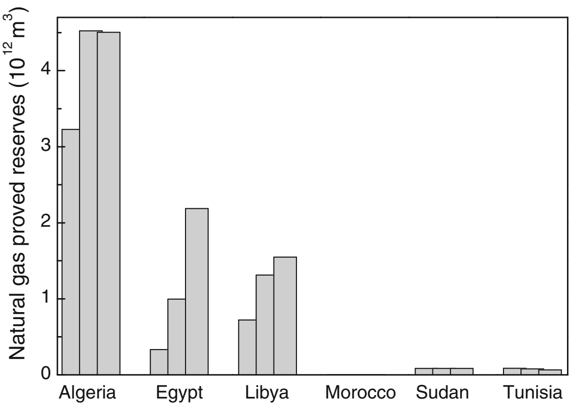


Table 5.1 Total recoverable coal [3]

Location	Quantity (10^6 short tons)
Algeria	65.04
Egypt	17.64
Morocco	134.48
Northern Africa	217.16

ninth in the world. The Algerian largest natural gas field is Hassi R'mel, which acts as a hub for natural gas production and holds about half of the total national reserves. The other fields are located in the Illizi, the Rhourde Nouss, Ghadames, and the Ahnet-Timimoun Basins. Egypt and Libya are the two other countries in the region with significant proved reserves while those for Sudan, Tunisia, and Morocco are very small. No proven natural gas reserves have been reported for Western Sahara.

5.2.3 Coal

As shown in Table 5.1, some reasonable amount of coal reserves are available only in three countries of Northern Africa, namely, Algeria, Egypt and Morocco. No sizable reserves are reported for the other countries and territories of Northern Africa. The most significant reserves that represent almost 60 % of the total coal reserves in the region are found in Morocco. The exploitation of these reserves were however limited and were subsequently discontinued by the beginning of this century.

The most significant exploitation was in Morocco, more particularly in Jerada on the Algerian border but production was also stopped altogether in 2001 for lack economic viability reasons. There is still some expectation in some North African countries that the exploitation of coal will resume in the near future to support thermal power generation schemes.

5.3 Non-conventional Hydrocarbon Reserves

Oil, natural gas, and coal are considered to be the conventional hydrocarbon reserves, but there are also non-conventional hydrocarbon reserves such as shale oil and shale gas which can be processed and used as fuel. Their use however is associated with more severe negative environmental impact especially water pollution, underground water contamination, emission of greenhouse gases and rise in seismic activity. Despite this knowledge, there is a growing worldwide interest in development of shale oil and shale gas resources. Successful commercial exploitation of shale oil and gas in some developed countries has motivated other nations around the world to do the same with their shale formation reserves. Exploration activities are underway in a number of countries, including Algeria and Egypt. Estimates put the technically recoverable shale gas in Northern Africa at 27.5 trillion m^3 and the technically recoverable shale oil at 38.1 Billion Barrels [3]. Details on these reserves by country are reported in Table 5.2.

Compared with the actual conventional gas and oil reserves, it can be seen that all the countries of Northern Africa, except Sudan, have potentially and technically viable exploitation of shale formations. With its estimated 20.02 trillion cubic meters technically recoverable shale gas, Algeria holds about 72 % of all Northern Africa shale gas reserves. It is ranked among the top five countries in the world having the largest technically recoverable shale gas reserves. If exploited, the shale gas resources would allow Algeria to increase its natural gas mix by a factor of four. With regard to shale oil, Libya has the largest technically recoverable reserves. Its shale oil resources represent about 68.5 % of the total technically recoverable shale oil reserves in North Africa.

These non-conventional hydrocarbon potentials have been reported only for the most promising sites. The assessments are still at their early stages, so the potential could be even higher particularly for Northern Africa. The most promising sites considered in Northern Africa are:

- The Tindouf Basinn, extending over four countries, namely, Algeria, Mauritania, Morocco and Western Sahara.
- The Tadla Basin, situated in central Morocco.
- The Timimoum, the Reggane, the Ahnet, the Mouydir and the Illizi Basins, all situated in the Algerian Sahara.
- The Ghadames/Berkine Basin which extends over three countries, namely Algeria, Libya and Tunisia.
- The Murzuq and the Sirte Basins, situated in Libya.

Table 5.2 Estimated technically recoverable shale oil and shale gas resources in Northern Africa [3]

Location	Shale gas resources (trillion cubic meters)	Shale oil resources (billion barrels)
Algeria	20.02	5.7
Egypt	2.83	4.6
Libya	3.46	26.1
Morocco	0.34	0
Sudan	–	–
Tunisia	0.65	1.5
Western Sahara	0.23	0.2
Northern Africa	27.5	38.1

- The Western or Libyan Desert Basins which include the Shoushan, the Alamein, the Matruh, the Abu Gharadig and the Natrun Basins (all are located in the Western desert of Egypt).

5.4 Renewable Energy Resources

There is substantial wind and solar energy resources particularly along the coastline and the mountain ranges where wind speeds are suitable for wind farm development. By its position in the Sun Belt, North Africa has one of the best solar energy potential in the world.

The most important renewable energy resources are solar, wind and geothermal energies. There are also biomass resources on which most rural communities depend for their energy supply but these are very limited. However, solar and wind energies, though intermittent in nature, are poised to play an important role in energy provision initiatives in Northern Africa. A good characterization of the potential of these two resources is then necessary not only for site qualification but also for optimum system design and technology selection. To this end, long term accurate measurements are necessary. This should result in high resolution maps as prerequisite tools for any viable exploitation of renewable energy. So far only Algeria has established a preliminary solar map. Efforts have also been made by Egypt to establish a wind map. In all the other countries, like in other parts of Africa, work on this still remains to be done.

5.4.1 Solar Energy Potential

Located in the sun-belt region, Northern Africa enjoys exceptionally high solar energy potential. This is so because a very large expanse of the region's land mass is desert where the sky is clear most of the time. In this region, daily sunshine duration ranges from 8 to 12 h/day giving an annual average of about 3500 h/year. Moreover, because of their geographic position, the variation in sunshine durations between different months of the year is fairly small for the inland sites. This gives favorable conditions for solar energy application all the year round.

According to preliminary solar maps produced in Algeria, sunshine duration is on the average equal to 7.3 h in the north, 8.3 h in the High Plateaus and in excess of 10 h in the south. The daily average value of the solar isolation goes from about 4.7 kWh/m^2 in the North to 5.3 kWh/m^2 in the High Plateaus and to about 7.7 kWh/m^2 in the south. However, solar measurements indicate that Egypt is endowed with higher solar potential with daily sunshine duration ranging from 9 to 11 h from North to south. Morocco which is at the western end of the region receives average daily sunshine of about 5.3 kWh m^{-2}. In Sudan, sunshine records are equally high with an annual mean daily global radiation ranging from 3.05 to 7.62 kWh/m^2 while in Tunisia it varies from 5 to 5.5 kWh/m^2. Western Sahara has even better average daily solar radiation in excess of 6 kWh/m^2. These values are way above the feasibility threshold, making the entire region very suitable for viable solar energy exploitation.

In order to compare the solar potential for the different countries of Northern Africa, the direct normal irradiance (DNI) and the global horizontal irradiation (GHI) for each country are reported in Fig. 5.5 and they confirm the excellent level of solar irradiation. Indeed the DNI in North Africa is way above the suitability threshold of 1800–2000 kWh/m^2/year. This indicates that solar thermal applications, more particularly, concentrated solar power, are viable in all Northern Africa.

Similarly for GHI, the threshold for suitability is in the range between 1000 and 1500 kWh/m^2/year, which is much lower than GHI in the five North African countries as shown in Fig. 5.5. This means that all these countries are suitable locations for solar photovoltaic applications. For CSP applications, the minimum yearly direct normal irradiance should be at least 1800 kWh/m^2/year. From Figs. 5.5 and 5.6, it is clear also that North African countries are all suitable for both PV and CSP applications with Sudan having the best conditions.

Solar energy applications include the use of Photovoltaic devices for electricity generation and thermal conversion devices for heat generation. Some of these may involve the use of solar concentrators to increase the efficiency of conversion. The total solar PV installed capacity in the region is 48 MWp (Fig. 5.7). Egypt and Morocco are the leading countries in solar PV applications. Their combined installed capacity is about 30 MW_p.

It should be noted that the installed capacities are generated using small scale units. Most applications focus mainly on rural electrification of remote areas, water pumping, street lighting, road beaconing and telecommunications.

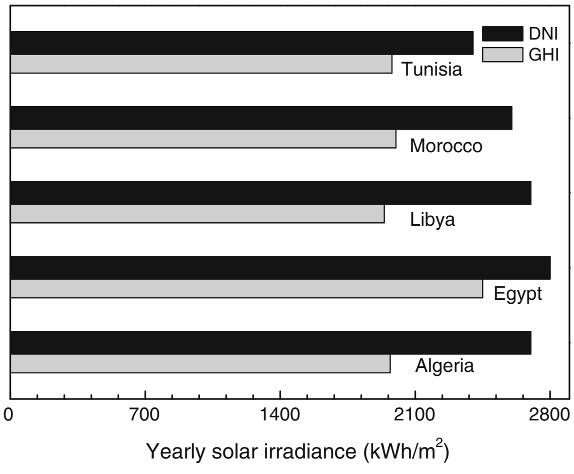


Fig. 5.5 Solar radiation in Northern Africa [18]

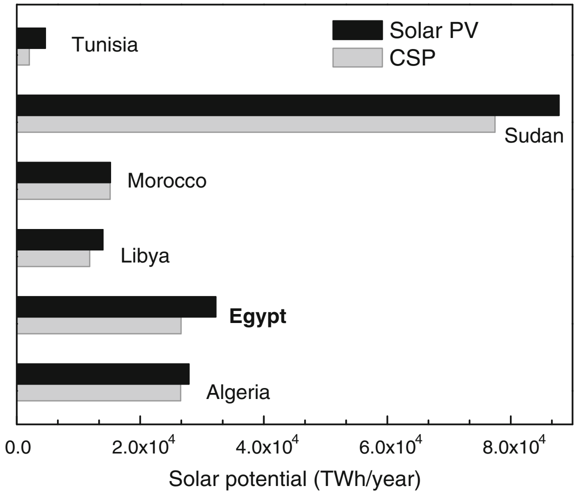


Fig. 5.6 Solar potential in Northern Africa [7, 18]

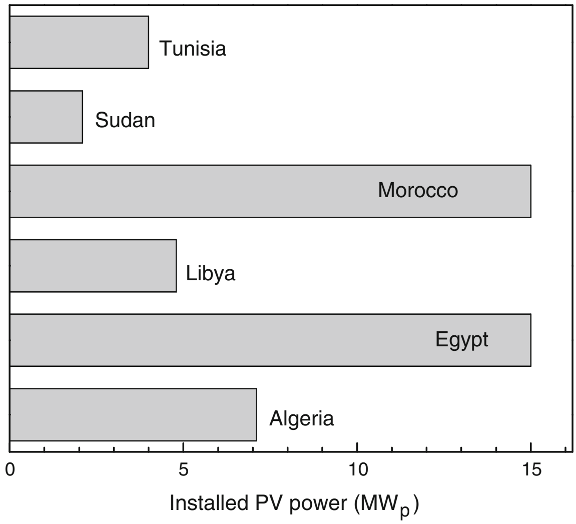


Fig. 5.7 Solar photovoltaic installed capacity in Northern Africa

Significant progress has been made in rural electrification in Northern Africa where the average electrification rate is over 97 %, excluding Sudan. There are few remote areas where there is still urgent need for electrification and the best options for these are mini grids or off-grid renewable based systems. In this respect, all the countries of Northern Africa have resorted to PV kits for the partial or total electrification of the remote areas. In Algeria, the rural electrification program is part of the national electrification program [9]. Its aim is to improve the living conditions of the remote rural dwellers, more particularly those of the Big South. The state is fully funding these electrification projects through the National Company of

Electricity and Gas (SONELGAZ). PV kits, with 1.5, 3 and 6 kW_p rated capacities, are respectively allocated to groups of 6, 10 or 20 homes. The kits provide energy for lighting, for domestic appliances, and for ventilation or air-conditioning.

About 58 % of the PV installed capacity is allocated to rural electrification, 21 % to powering telecommunication sites, 12 % to water pumping, 2 % to public lighting and the remaining capacity to other activities such as water desalination and road beaconing. Most of the North African countries are engaged in these solar electrification projects. In Libya, rural electrification using PV systems is under the National Plan for Rural Electrification and several remote villages with scattered houses have been electrified [16]. Similar activities using various PV kits are going on in Morocco, Tunisia and Sudan.

There are also some on-going activities in concentrating solar power systems. Concentrating Solar Power systems usually make use of several parabolic trough collectors and are used to produce steam, which is used for various applications including electricity generation. It is however more expensive and therefore most countries have not ventured into it in a large scale. Only three countries, namely Algeria, Egypt and Morocco, have engaged in CSP development. Tunisia has also been reported to be planning the construction of some CSP units. The region, in general, is also engaged in the applications of other solar systems such as solar thermal plants and water heaters.

The first Moroccan solar thermal plant was erected at Ain Beni Mathar, close to the Algerian border. This site is close to the Maghreb-Europe Gas Pipeline, which transports the Algerian natural gas to Europe. The location ensures that gas is always available for the power plant and that the power produced is also easily conveyed to the power line. There is also plenty of water for cooling and the DNI is important. The Solar Power plant covers a total area of about 160 ha and includes two 150 MW gas turbines and one 120 MW steam turbine. It is designed to deliver 3538 GWh/year.

In Algeria, the first solar thermal plant was erected in HassiR'Mel in Northern Sahara. This site has many advantages as it is located next to the HassiR'Mel, the largest gas field in Algeria and the generated power is for the gas field site, which is just "next door." The plant includes two 40 MW gas turbines and an 80 MW steam turbine and was designed to produce about 1250 GWh/year. The first Egyptian solar thermal power plant was located in Kuraymat, south of Cairo, on the east bank of River Nile. The plant which was designed to generate about 34 GWh/year includes two 40 MW gas turbine and a 70 MW steam turbine. In all the cases of solar thermal power plants in North Africa, the sites chosen are flat and so the DNI is very high in each case.

Solar water heaters are some of the simplest and reliable solar energy devices. Heating consumes a lot of electric power and therefore solar water heaters are generally used to save on the cost of electricity. Solar water heater application is not at the same level in all the countries in the region. It is more successful in Tunisia than in any other country and this is probably due to the promotional activities and other incentives provided by the state in addition to investment incentives given to the investors in the production and distribution chain. Most North African countries are actively engaged in some form of solar energy promotional activities and incentive frameworks that will see the region advance in renewable energies faster than the rest of Africa.

5.4.2 Wind Energy Resources

Given the improvement in technology, wind has become a popular alternative source of energy to conventional energy resources. For Northern Africa, wind is the other major renewable energy resource and wind measurements have indicated that there are several attractive areas for wind energy exploitation. The most promising sites are located on the Red Sea and the Atlantic coasts. The Suez Gulf in particular has exhibited annual wind speeds way above the suitability threshold.

In Algeria, an assessment of wind potential has shown that the most promising sites are located in the southwest region more particularly around Adrar. They are also found in the north-west of Oran, in the east for the region stretching from Meghres to Biskra and in the western region stretching from Kheither to Tiaret. For the rest of Algeria, the wind potential ranges from weak to moderate.

Egypt enjoys reasonable wind energy resources particularly along the Suez Gulf region. Wind speed studies have shown that Egypt, Western Sahara and Morocco are the best locations for wind energy development. Libya and Tunisia also have suitable wind sites along the Mediterranean coastline. Similarly, Sudan has a number of suitable sites along the Red Sea coastline. Thus, North Africa has considerable wind and solar energy potentials in Africa.

In order to evaluate the capacity of the wind resources, it is necessary to analyze yearly full load hours. This is shown in Fig. 5.8 for the different countries of Northern Africa.

Data provided in Fig. 5.9 clearly indicate that the potentials are good enough for wind energy exploitation in the region.

The oldest use of wind power was the application of small installations for water pumping. There are a fairly large number of these installations scattered all over Northern Africa, particularly for land reclamation and rural development.

Of all the renewable energy resources used for electricity generation, wind power is the fastest growing technology. In North Africa, this is particularly true for Egypt, Morocco and Tunisia. Figure 5.10 indicates the evolution of the total wind installed capacity for Northern Africa. In 2013, the total installed wind power in Northern Africa was 1179 MW. This represented 79.3 % of the total African wind power capacity but was only 0.33 % of the world wind power capacity. Morocco and Egypt are the two major wind power countries in Northern Africa. Their combined installed capacities amount to 87.3 % of the total Northern Africa production. Egypt contributes 46 % of this while Morocco's contribution is about 41.3 %. At the African level, the shares in wind capacities of Egypt and Morocco are respectively 37 and 33 %. This means that, in Africa, 70 % of all the produced wind power is produced by Egypt and Morocco [17].

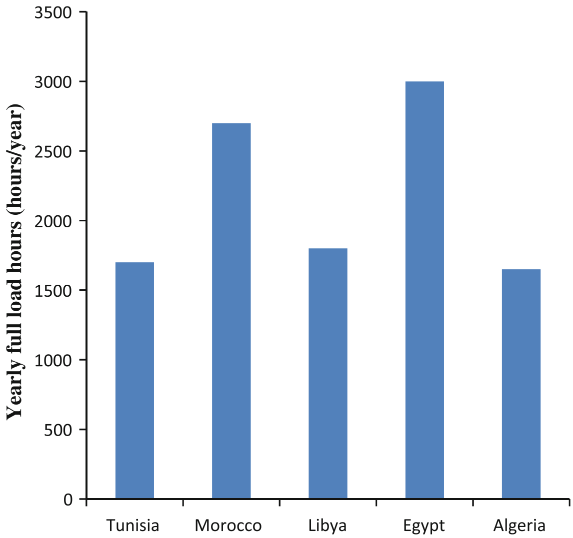


Fig. 5.8 Wind yearly full load hours in Northern Africa [4, 5, 7]

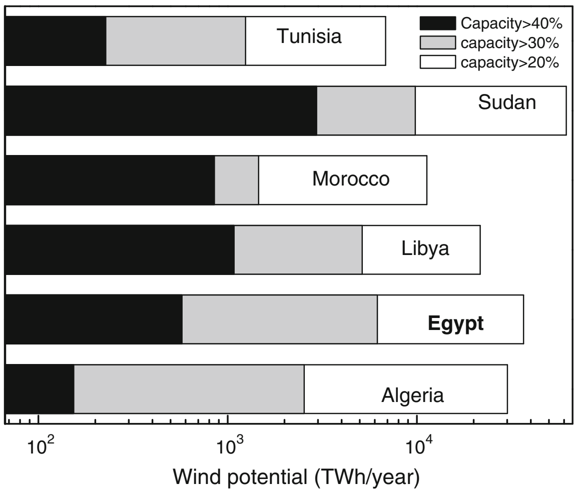


Fig. 5.9 Wind potential in Northern Africa [4, 5, 7]

The zone with the highest concentration of wind energy conversion systems is Zafarana in Egypt with 698 units. The region of Tangier-Tatouan in northern Morocco has 256 units while the region of Bizerte in north-east Tunisia has 163 units. Algeria has lagged behind with only one wind farm established in Adrar.

The Egyptian installed wind capacity is concentrated in the Zafarana wind farm with a total installed capacity in excess of 544 MW, making it the largest wind farm in Africa. Morocco and Libya have total wind installed capacity of 495 and 20 MW respectively while Tunisia has total installed capacity of 104 MW [14]. Most of the North African countries have plans to expand wind energy utilization in the region.

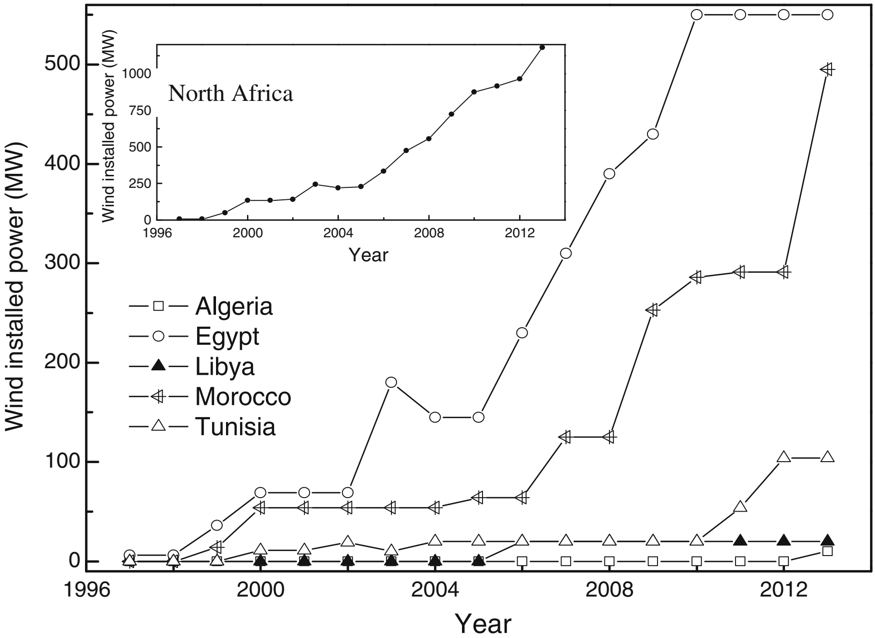


Fig. 5.10 Development of wind power in Northern Africa

5.4.3 Geothermal Energy Resources

Studies on geothermal occurrence in North Africa has not been extensively conducted, but some general studies indicate that the available geothermal resources are of low enthalpy types with temperatures not exceeding 80 °C, which is too low for power generation. A few sites especially in Hammam Meskhoutine in Algeria have been found to have geothermal temperatures within 90–100 °C range but their pressures are not sufficient for power generation. Sites with similar features have been identified in different countries in the region including Morocco, Egypt, and Sudan but their exploitation for power generation appear to be unviable [2, 10, 19].

Geothermal energy can be used for different purposes depending on the temperature of the source. Resources with high temperature in excess of 220 °C are better suited for Power generation while those with lower temperature are typically meant for direct heating. For power generation from high temperature resources, two technologies are in use. There is the dry steam technology where steam from the geothermal reservoir is fed directly to the turbine unit to generate electricity. The second technology is the flash steam in which geothermal hot water, pumped at high pressure, is converted to steam by a sudden drop in pressure. The steam is then directed to the turbine for electricity generation.

Direct use is for non power applications and include balneo-therapy, greenhouses, district heating, aquaculture and industrial process heating. In Northern

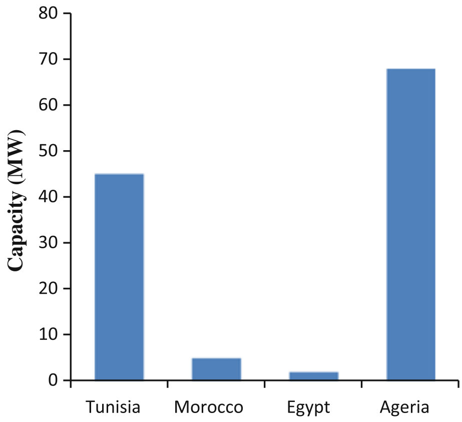


Fig. 5.11 Direct use of geothermal energy in North Africa [11]

Africa, the use of geothermal hot springs for bathing is a tradition that has been going on for centuries.

Figure 5.11 shows the direct geothermal energy application capacities of different countries in North Africa. From this figure, it is clear that geothermal use is dominated by Algeria and Tunisia. The capacity of both countries amount to almost 95 % of the total Northern Africa capacity in which Algerian has 57.3 % while Tunisia has about 37.7 %. It should also be noted that Northern Africa dominates the geothermal energy direct-use in Africa. But geothermal application for power generation in Africa is dominated by Eastern Africa.

There is no recorded use of geothermal energy by either Libya or Sudan. Geothermal applications are still in their early stages but progress is being made to expand this application in the region particularly in balneology, swimming pools and potable water bottling. In Egypt, the geothermal applications are still at a low level while Tunisia is the African leader in the use of geothermal energy for greenhouse heating and agricultural land irrigation. More information on geothermal potential and applications in North Africa for specific countries are available [6, 8, 12, 13, 19].

5.4.4 Biomass Energy Potential

North Africa is a region dominated by desert type of condition and therefore arable land and vegetation cover are scarce. This obviously implies that biomass materials that can be used as energy resource may not be readily available and use of whatever little available is tightly controlled and restricted by law. There are a few sites such as the Nile Valley, the highlands, and coastal regions where biomass is available. In such areas, energy crops such as jatropha can be grown and indeed there have been cases where some countries in the region have considered production of bio-diesel and ethanol from energy crops. Some of these crops like

Jatropha are well adapted to arid and desert climate and can grow on poor land that is usually not reserved for production of food crops. They can also withstand drought and can survive on as little as 250–300 mm of rainfall per year. However, in a region where there is already a deficit of farm land and water, dedicated energy crop cultivation can seriously compromise food security for the communities. However, in areas that are already under food crop production, agricultural residues can be used as sources of biomass energy. In North Africa, some of these crops are the cereals (wheat, barley, maize, rice and sorghum and millet), sugar crops (sugar cane and sugar beets), olive groves and date palms. In this respect, Egypt has the highest biomass potential in the region followed by Morocco and Sudan, particularly from sugar cane and cereal crops. Figure 5.12 gives details of these crops in the region for the year 2011.

Date palm and olive are also widely cultivated in North Africa and they do generate residues, which are the most significant resources with high biomass potential. They are well suited to the semi-arid and arid climate of the region. Morocco and Tunisia are the leading olives producers while Egypt and Algeria lead in dates production (Fig. 5.13). Thus biomass applications are limited to agricultural

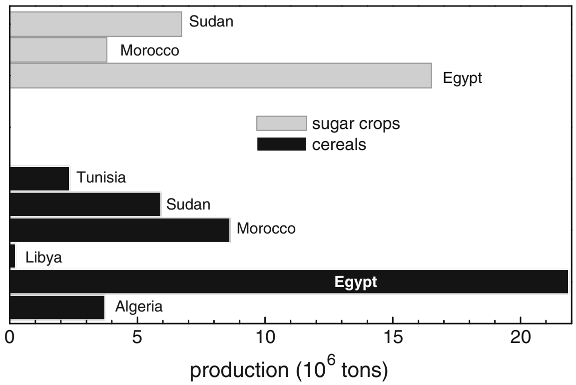


Fig. 5.12 Cereals and sugar crops production in North Africa [1]

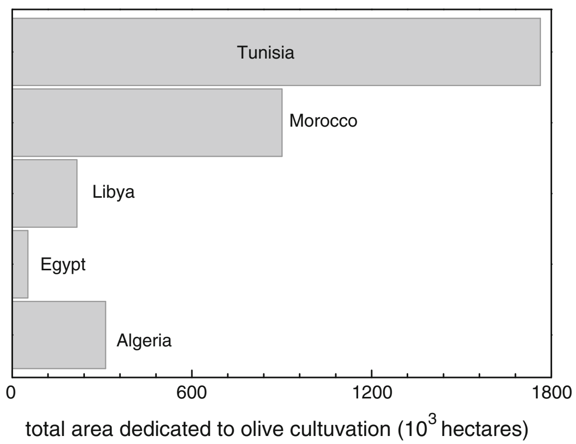


Fig. 5.13 Total area covered by olive groves in Northern Africa countries [1]

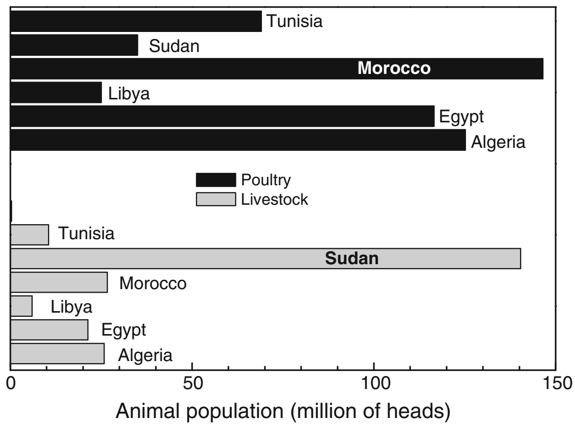


Fig. 5.14 Animal population in North Africa [20]

crops, which are grown in the region and, as indicated, these are cereals, dates, olives and sugar crops. Biomass situation in North Africa is therefore quite different from that of Sub-Saharan region where there are abundant biomass materials from natural forests and other vegetation.

Another possible use of biomass resources in the region is through production of biogas from animal wastes. Similarly wastes from poultry can also be used as raw materials for biogas plants. North Africa has a variety of livestock that include cattle, sheep, camels, goats, horses, mules, asses and pigs. The potential of animal wastes depends on the animal type and the amount of waste produced. Figure 5.14 shows livestock and poultry populations for Northern Africa countries. The numbers for Sudan include those of Southern Sudan. The total population of livestock and poultry are 231 million and 517.2 million respectively. Studies have indicated that biogas yield from cattle waste is about 6.5 GJ per head per year. With a total cattle population of 55.2 million only, biogas potential is about 358.9 PJ per year in Northern Africa.

It should however be noted that, in terms of fraction of land covered with forests, Sudan has more forest cover than all the Northern African countries and therefore there is a large percentage of rural population depending on biomass as a source of energy (see Fig. 5.15).

5.5 Planned Energy Developments and Targets

North African countries have well defined plans for developing renewable energy resources and have set targets to achieve their respective goals. These are shown in Table 5.3.

In Table 5.3, the targets and the target dates for each country are reported. The third column shows the share of renewable energy in electricity generation in different countries. For Tunisia and Morocco, it is the share of installed capacity,

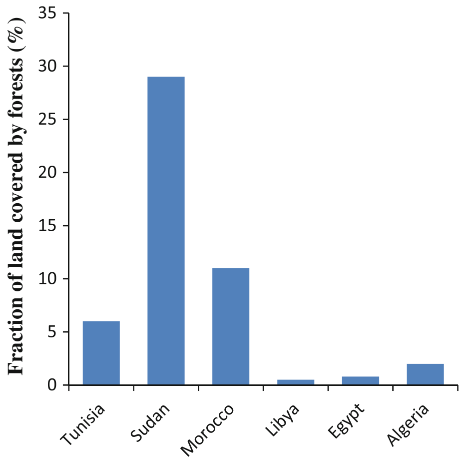


Fig. 5.15 Fraction of land covered by forest in North Africa [20]

Table 5.3 Targets for different renewable energy sources for North Africa

Country	Target date	Target (%)	Wind (%)	PV (%)	CSP (%)	Hydro (%)	Biomass (%)
Algeria	2030	40	6.8	9.2	24	–	–
Egypt	2020	20	12.7	0.39	1.94	4.94	–
Libya	2025	10	4.5	3.8	1.7	–	–
Morocco	2020	42	14	14		14	–
Sudan	2031	11	4.73	4.64	0.35	0.44	0.84
Tunisia	2030	40	17	5	15	–	3

which basically gives similar information as for the other countries. The shares of each type of renewable energy, i.e., wind, CSP, PV, hydro and biomass are also reported. The most prominent renewable energy sources to be developed by the different countries of North Africa are wind and solar.

It is noted that only Sudan and Tunisia have made some projections for the development of biomass potential for power generation. On the other hand, Algeria, Libya and Tunisia have not set targets for power generation using their hydro potentials. In the case of Sudan, the share of hydropower is expected to go down. In both cases, this could be explained by the limited potentials of these two renewable sources. Indeed, in the region which is over-whelmingly desert, arable lands and rivers are limited. River resources have been over stretched by agricultural and domestic demands and so any further utilization of the rivers for energy crop production would lead to the decrease of the potentials of the rivers and compromise their future contribution in general. The region is therefore concerned about other alternative energy resources and would make serious efforts to develop them. For example, Algeria is addressing this by making plans to develop its geothermal potential for power generation.

For solar, the two main technologies, photovoltaic and CSP, are already under serious considerations by all the North African countries. Algeria and Egypt have set ambitious targets for the growth of CSP and PV capacities.

The information given in Table 5.3 also proportionately reflects the share of each renewable energy source in North Africa. Evidently, wind energy has generated more interest than solar systems in the region and most countries have not only established operational wind power facilities but have also set achievable wind energy targets. Using the reported data, the average annual growth of renewable energy that should be sustained to reach the target has been evaluated. The results are reported in Table 5.4. It can be seen that the largest average annual growth will occur in Algeria.

It is worth noting that as each country implements its own plan to meet the set targets, the energy mix would determine the level of contribution from each source. This implies that the use of energy from some existing sources would either go up or even drop depending on the level of attention given to the development of each source. For example, if a particular country wants to move away from hydropower source, then production capacity from hydro would go down.

Different countries have established renewable energy development frameworks with action plans that are expected to lead them to the goals before or on the target dates indicated on Table 5.3.

Some of the action plans include the establishment of local manufacturing of some energy devices. For example, the establishments of local plants with sufficient capacities for producing photovoltaic modules and CSP that would satisfy the planned local demand rate have been considered in the region. Similarly, plans are underway to set up wind farms, geothermal power plants, PV and CSP plants at various selected locations in the entire North African region. This is a sign that the region is determined to increase the exploitation of renewable energy resources despite the availability of abundant hydrocarbon fuels in the region.

Some of the admirable features of the North African renewable energy development plans include the need to build local capacity for both development and management of renewable energy facilities. This is expected to enhance the local renewable energy industry not only to reach the set targets but also for future expansion of the sector. Already, there are a number of local solar water heater,

Table 5.4 Evolution and average annual growth rates of renewable energy source in Northern Africa

Country	RE capacity in 2012 (MW)	RE capacity at target date (MW)	Average annual growth (%)
Algeria	253	12,000	23.9
Egypt	3385	11,320	16.3
Libya	0	2219	–
Morocco	2119.4	6000	13.9
Sudan	1590	1582	−0.03
Tunisia	244	4000	16.8

Concentrating Solar Power and Photovoltaic industries at various levels in the region. All these plans are aiming at increasing the share of renewable energies in the individual country's national energy mix with a view to having wind and solar generation facilities take the lead in electricity production.

5.6 Energy Supportive Policies

Obviously many of the plans and targets set for the development of renewable energy industry cannot succeed if there are no local capacities, resources, and supportive national policies. This becomes more important for renewable energy industry given that it is still a relatively new sector for most African countries. Aware of these challenges, the countries of Northern Africa have developed various instruments to spur renewable energy programs. The most common among these instruments are:

Power purchase agreements bidding (PPA): this is a process by which an area with natural resources is identified and reserved for private investment. The investor is selected through a government—led tendering process. The power purchase agreements bidding exists for large-scale private renewable projects in Algeria, Egypt, and Morocco but is yet to be instituted in Libya and Tunisia.

Feed-in Tariffs: Also known as premium payments, advanced renewable tariffs or minimum price standards. It is a worldwide common instrument used to support renewable energy power generation ventures. Feed-in Tariffs is a fixed price purchase guarantee for a specific technology over a given period of time and may incorporate some element of subsidy to offset the high production costs.

Net metering: This is a mechanism that permits the renewable energy producers to feed the excess electricity to the grid. The amount of electricity fed to the grid is reduced from the monthly bill. It is preferred by small scale energy producers for private residential or commercial use. This policy is in effect in Egypt and Tunisia but not in other countries in the region. It is however possible in Morocco but with some conditions.

Financial incentives and Funds: Can be in the form of tax measures, play an important indirect role in reducing the overall cost of a renewable energy investment. In Northern Africa, Algeria, Egypt, Morocco, and Sudan have introduced some financial incentives. Such incentives are not available in Libya and Tunisia.

Establishment of renewable energy funds: This is special funds established for shaping the renewable market by contributing, for example, to the strengthening of R&D in the field, the creation of innovative small enterprises and industries and the setting up of standards and norms. Such funds have been set up by most of the countries in Northern Africa (Tunisia, Algeria, Morocco and Egypt).

Dedicated Agencies: Renewable energy agencies have been adopted worldwide as instruments in the effective deployment of renewable energy projects. They are institutions with great ability to influence and even design renewable energy programs, administrative procedures, facilitation, assistance in project implementation, R&D enhancement, capacity building and industrial development. All the countries in Northern Africa (except Sudan) have dedicated agencies. Similar policy frameworks have been publicly announced in some Sub-Saharan African countries but they still lack the drive, commitments and institutional arrangements for their implementation.

For North Africa, in addition to policy frameworks, there are also a number of institutions that have sprung up as a result of increased interest in renewable energy development. The establishments of these institutions are good signals that the region is indeed serious about adopting renewable energy culture. Examples of such institutions are shown in Table 5.5.

There are also a lot of activities in renewable energies that are going on in most of the universities in the region.

The energy situation in North Africa and the region's energy development plans should be a good example not only for Africa but also for the world in general. But still there are certain issues that should be seriously considered. It was noted in Chap. 1 that global energy demand is continually increasing and North Africa is not exceptional. As a result of this, high energy consumption and declining conventional energy reserves is introducing a new different scenario in energy mix practices in Northern Africa. For the net energy importing countries such as Morocco and Tunisia, the energy demand is becoming a heavy burden and it is putting a lot of pressure on the economy.

For countries, such as Egypt, the current level of production of fossil fuels is barely sufficient to meet the local needs. This situation requires a serious re-examination of possible alternative energy resources. For hydrocarbon exporters, such as Algeria and Libya, the growing needs and the declining reserves are hampering the economic development. For Sudan, the situation is even worse as the country suddenly lost two thirds of it hydrocarbon energy resources after the secession of South Sudan.

Most Northern African countries have large parts of their territories in the desert where rainfall and water bodies are scarce and so they suffer from recurrent droughts. This makes hydropower resources less reliable in these countries. It is of course true that for the Nile valley countries such as Egypt and Sudan, the Nile

Table 5.5 Research institutions in the renewable energy field in Northern Africa

Country	Institution
Algeria	Renewable Energy Development Center (CDER)
	Research Center in Semiconductor Technology for Energy (CRTSE)
	Electricity and Gas Research and Development Center (CREDEG)
Egypt	Energy Research Center, Cairo University
Libya	Center for Solar Energy Research and Studies (CSERS)
Morocco	Solar and New Energies Research Institute (IRESEN)
	National Center for Scientific and Technical Research (CNRST)
Sudan	National Center for Energy Research (NCR)
Tunisia	Research Center and Energy Technologies (CRTEN)

offers some potential for hydropower generation but suitable sites for other renewable energy development are limited.

As for fossil fuels, besides their damaging effects on the environment, they are not fairly distributed to all countries. Definitely fossil fuels play a strategic role in the development for those countries which have them, but these resources are finite and will be depleted in future. For the other countries, the importation of these fuels is a heavy financial burden on them, forcing them to neglect the provision of important services to their people. Therefore, seeking the solution in renewable energy resources is a process that all countries should take very seriously whether they have hydrocarbon fuels or not.

5.7 Focus on Individual North African Countries

So far the discussion has covered Northern Africa in general and this is quite in order due to their common geographical and climatic features such as the Sahara Desert which spreads into most of these countries. It is however important to also give a summary of the energy situation in each individual country in the region and how they generate power. In doing this, it should be expected that some information may be repeated in order to improve clarity.

5.7.1 Morocco

Morocco is the largest net energy importer in the region. It has some natural gas and had about one million barrels of oil reserves in 2006, but imports significant amount of crude oil, which it then refines in the country. It also imports coal, mainly from South Africa, which is used for electricity generation. In an effort to reduce dependence on imported fuels, it has an elaborate renewable energy plan targeting solar and wind energies. Total renewable energy capacity was 300 MW in 2011—enough to supply some African countries with all electricity requirements. Contribution from renewable energy is expected to rise to over 40 % of the total electricity by 2020 when wind, solar and hydro are each expected to contribute 14 % corresponding to about 2000 MW from each of these resources. In 2014, installed wind power alone was estimated to be slightly over 1000 MW and there is sufficient wind and even solar for further development. Presently, Morocco is a major renewable energy user and is therefore one of the countries that are making great efforts in renewable energy development in Africa.

5.7.2 Egypt

Egypt is an oil producing country and had the sixth largest oil reserves in Africa. Most of its oil is found in the Gulf of Suez followed by the Western Desert, Eastern

Desert, and Sinai Peninsula. Egypt is also a strategic country for oil transportation to markets in different parts of the world. This advantageous position was, in the past, used effectively to export oil from the oil-rich region but, due to political and economic instability, the situation changed. Furthermore, oil production in Egypt has continued to drop to the extent that the country began to struggle to meet its own oil requirements. In 2013, most of its oil reserves of 4.4 billion barrels and about 2.6 trillion m^3 of natural gas were used to meet the growing domestic energy needs.

In 1996, production level stood at about 935,000 barrels a day but by 2005, this had dropped to about 726,000 barrels per day. The country's several oil refineries are collectively capable of processing all this crude oil per day. The downward energy production trend and increasing domestic demand have forced Egypt to significantly reduce its oil export and so denying the country the much needed foreign earning. Since 2006, almost all Egyptian oil has been consumed domestically while about 60 % of natural gas is used locally. To appreciate the role of fossil-based fuels in Egypt, it is worth mentioning that over 90 % of Egyptian energy needs are met using oil and gas. Gas appears to be the main source of the county's hard currency. Egypt has Liquefied Natural Gas (LNG) plants which process LNG which, together with natural gas are exported through Arab Gas Pipeline to the Middle East. It is expected that this pipeline will in future play a significant role in facilitating gas export to Europe. Egypt also has an appreciable amount of shale oil.

Availability of gas in the country has enabled Egypt to generate most of its electricity using gas fired machines. In 2006, electricity total installed capacity was 18 GW (18,000 MW), making Egypt one of the largest electricity producers in the region. Since 2002, Egypt has assumed its right position as a leading electricity producer and has played a key role in coordinating electricity distribution in the region which includes Jordan, Syria, Lebanon, Iraq, Libya, Tunisia, Algeria and as far as Morocco. Like other large energy consumers, it has, for a long time, been considering the use of nuclear energy in order to increase its electricity production. In 2006, however, of the total installed capacity, 72 % was from gas, 16 % from oil and only 11 % from hydro sources mainly from Aswan Dam. A small fraction was produced from other sources such as wind and solar. The situation is bound to change since the Egyptian energy demand for electricity is rapidly growing at a rate of about 1500–2000 MW a year due to rapid urbanization and economic growth. As a result of this, Egypt is suffering from severe power shortages necessitating the need to look for alternative energy options especially given the fact that over 80 % of the hydro capacity has been developed and oil and gas supplies are also strained. Egypt is therefore focussing more on wind and solar energies.

Like most African countries, Egypt has abundant solar energy and is already using photovoltaic systems in various sectors including water pumping, desalination, telecommunications and rural electrification. The average level of solar radiation is between 2000 and 3200 kWh/m^2/year and there are more than 5 MW of PV systems in use. The country also has a significant amount of wind energy potential especially along the coast of the Red Sea. Some of the regions with suitable wind speed regimes include Zafarana district, Gulf of Suez, East and West banks of Nile river. In 2010, Zafarana district where wind speeds get up to 9 ms^{-1} had installed wind energy capacity of about 550 MW while Gebel el-Zayt area where wind speeds can get up to 11 ms^{-1} is also poised to be a major wind farm area [5].

About 660 MW of wind energy generators are in use in the country and the target is to reach 7200 MW of wind power by 2020.

Thus renewable energy has received a lot of attention since the 1980s when its development strategy was formulated as an integral part of national energy planning. New and Renewable Energy Authority (NREA) was also established to act as a national focal point for developing renewable energy technologies in Egypt. This showed that the government is committed to the promotion of renewable energy.

5.7.3 Algeria

In the previous general section of this Chapter, Algerian energy resources were considered in a little more detail to give a typical example of the North African energy situation. So only a brief account is given here. Algeria is perceived to be the largest in Africa in terms of its area but its population was only about 40 million people in 2014. It has abundant energy resources that include oil reserves of about 13.4 billion barrels, natural gas of 4502 billion m^3, coal reserves of 65 million short tons and solar energy radiation potential of about 8 billion MWh/year. Algeria is a leading producer and exporter of natural gas and its energy mix is almost exclusively based on fossil fuels in which natural gas contributes about 93 %. It also has enormous renewable energy potential particularly solar. Like most other African countries, it has plans to generate over 22,000 MW from renewable energies by 2030. These include solar, wind, biomass, geothermal and hydro. Already there are several solar energy facilities in use in Algeria. Both Algeria and Morocco have been working on a plan to export electricity from renewable energy sources to Europe. Out of wind energy potential of 35 TWh/year, it has developed wind farm of only 10 MW. Its biomass resources include solid wastes, crop wastes and some forest residues.

5.7.4 Libya

Libya is the second largest North African country by area but its population density is very low at a total of only about 6 million people in 2013 and only 22 % of this live in the rural areas. Its economy is driven by its abundant oil and natural gas reserves which contribute more than 90 % of its export earnings. In 2012, the main export destinations were Italy (23.5 %), Germany (12.5 %), China (11.3 %), France

(9.7 %), Spain (7.6 %), U.K. (4.7 %) and USA (4.5 %). Since most of its territory is either desert or semi-desert, Libya uses most of its export earnings to import food and other consumable goods. In 2011, it was producing more than 3 million barrels of oil per day from proven reserves of about 44 billion barrels. This was more than three times what its neighbouring country Egypt was producing. Note that proven oil reserves in Libya were also estimated to be 48.47 billion barrels in 2014. Practically all electricity consumed in Libya is generated from fossil-based fuels (mainly oil and gas). The total electricity installed capacity in 2010 was about 6800 MW enabling 99.8 % of its total population to have access to electricity. This is the highest electricity access rate in Africa which translates to a per capita energy consumption of about 3.7 MWh in Libya. Most of its cities are supplied with electricity through national grid network while remote villages use isolated diesel power generators. There is also some grid interconnection with Egypt.

Libya has no significant inland water resources such as rivers, which could be used for power generation or for meaningful agriculture. Furthermore, the vegetation cover is limited to the Mediterranean coastal line. The fact that it has been able to meet all its energy needs from oil and gas has, to some extent, relegated the renewable energy initiatives to the peripherals of mainstream energy concerns. Furthermore, energy prices are heavily subsidised in all economic sectors making it difficult to develop renewable energy technologies on a cost-effective basis. Installed photovoltaic capacity was only about 5 MW in 2012 and no significant wind energy installations, and since there is no incentive for renewable resources, it has relatively lower targets for renewable energies. In addition, the energy sector is not fully open to private investors. It is however estimated that Libya has a great potential for solar energy with a daily average solar radiation ranging from about 7.1 kWh/m^2/day on a horizontal surface in the North to about 8.1 kWh in the southern region. Similarly, wind energy potential is very good in many regions in Libya especially the coastal strip where average wind speeds range from 6 to 7.5 ms^{-1}. But, like solar, this potential has not been seriously exploited despite the fact that in many oasis wind energy has been used to pump water since the 1940s [15]. Table 5.6 illustrates the low profile of renewable energy contribution in Libya from 2009 and the projection for 2020.

Table 5.6 Renewable energy contribution in North Africa [7]

Country	Share in 2009 in %	2020 Strategy in %
Egypt	10	20
Morocco	14	42
Algeria	0.8	5–6
Tunisia	1.1	11–15
Libya	Negligible	Not specified

5.7.5 Tunisia

Tunisia is a small Northern African country with an area of about 163,610 km^2 but its population density is high at a total of 10.7 million people in 2012. It borders the Mediterranean Sea with the Atlas Mountains occupying its northern part while the southern part is generally arid throughout the year. Thus the climate ranges from the Mediterranean type in the north to Saharan-continental type in the south. It has fairly strong winds blowing from the south to the north with wind speeds that can reach up to about 25 ms^{-1} in spring and autumn. Tunisia has proven oil reserves of about 0.43 billion barrels and gas reserves of about 75 billion m^3 but production, particularly of oil, has been declining over the years from 120,000 barrels per day in the 1980s to about 67,000 barrels in 2012. Its oil refinery has a distillation capacity of about 34,000 barrels per day and this is not enough to meet domestic demand and so it has been planning to build another refinery. In 2011, it produced about 2.3 billion m^3 of its own natural gas. It also receives some natural gas from the Trans-Mediterranean Pipeline, which transports gas from Algeria to Italy through its territory. Most of its electricity is generated from fossil-based fuels while a small portion is generated using renewable energies mainly wind and hydro.

The total electricity installed capacity was about 4024 MW in 2011 out of which 3900 MW was produced from thermal power station fired by fossil-based fuels while 62 and 53 MW were obtained from hydro and wind respectively. For thermal stations, natural gas contributed 93 % while oil contributed only 7 %. In 2012 the use of renewable energies in electricity generation increased to 154 MW from wind, 66 MW from hydro and 4 MW from photovoltaic systems. Transmission of power is done mainly by *Societe Tunisenne d'Electricite et du Gaz* (STEG) and there are some independent power producers (IPPs) feeding electricity into the national grid. Large power consumers are encouraged to generate electricity for their own use and are encouraged to feed the surplus to the national grid under some special power purchase agreements. This arrangement has made it possible for Tunisia to increase access to electricity to 99.5 % of its population by 2012. Like other northern African countries, there is some interconnectivity with grids in other neighbouring countries but, this notwithstanding, Tunisia has set very ambitious plan for the exploitation of renewable energies and intends to have a total installed wind and solar energy capacity of about 1000 MW by 2016. This is to be achieved through newly identified priority areas such as expansion of wind power for electricity generation, introduction of incentives for use of solar energy, use of solar energy for irrigation and rural electrification, and encouragement of use of geothermal and small-scale hydropower plants. Tax incentives include reduction of customs and exemption of VAT on imported energy-related equipment or locally manufactured materials. Tunisia is therefore poised to become one of the major users of renewable energies in the region.

5.7.6 Sudan

For many years, the Republic of Sudan went through internal civil war between the Christian dominated South Sudan and the Islam dominated North Sudan. In 2011, South Sudan was allowed to form its own independent state and so the country was officially divided into two independent states namely Sudan (sometimes referred to as North Sudan) and South Sudan. In 2014 the population of Sudan was 39 million people while that of South Sudan was 11.8 million. Since this division, there still remained many issues that had not been fully agreed upon by both Sudan and South Sudan especially with regard to their common border and the ownership of the resources therein such as oil fields. In fact, in 2014, there was still internal ethnic fighting in South Sudan. So, for the purpose of energy resources analysis, Sudan is considered as one Country but each country is given due credit whenever possible.

A large part of the country is in the Sahara desert having a common border with Egypt in the North, Eritrea and Ethiopia in the east and Uganda and Kenya in the south. Proven oil and natural gas reserves, in 2010, were about 6 billion barrels and 3 trillion cubic feet, respectively. Before 2008, Sudan was a net energy exporter but oil production in Sudan and South Sudan has been declining because of natural declines at maturing fields. Sudan therefore set ambitious goals to increase production from new fields and to increase recovery rates at existing fields, but production continues to fall short of Sudan's goals. Furthermore, full capacity production of these fuels had been hampered by the many years of civil war during which Sudan also faced economic sanctions from Western countries. Thus the production of oil and gas in Sudan faced a lot of challenges. The effect of these was the partial or temporary withdrawal of Western European-based and American-based oil companies and the decline of production. The country had no option but to allow oil companies from China, India and Malaysia to have some stake in oil fields and pipelines. National oil companies such as Sudapet in Sudan and Nilepet in Southern Sudan also had some small take in the sector. In addition to fossil based fuels, Sudan has a significant hydro power potential from River Nile mainly provided by the many cataracts downstream of Khartoum, the capital city. Despite this opportunity, access to electricity has been less than 30 % in the whole Sudan. In South Sudan access is less than 5 % while in the north, it is much higher. The rural population, however have severe energy access problems and receive inadequate supply of power for lighting, heating, cooking, cooling, water pumping, radio or TV communications and security services. The supply of petroleum product, including diesel, kerosene and LPG are irregular and are often subjected to sudden price increases. Because of the inadequate supply of these fuels, women trek great distances into the forests to collect fuel wood, charcoal and agricultural residues. These account for more than 50 % of the total energy consumption.

5.8 Eritrea

The State of Eritrea is a small country in the horn of Africa along the shores of the Red Sea. It had a population of about 6.5 million people in 2014. So far no significant amount of fossil-based fuels is being exploited in the country but it is believed that Eritrea is actually sitting on massive oil and gas reserves. It is however still relying on imported oil and oil products for electricity generation, which stood at an installed capacity of 140 MW in 2013. Wind speed regime in the region especially along the shores of the Red Sea is very favourable for the development of wind farms. The same thing can also be said about some Eritrean highlands where wind speeds are in excess of 7 ms^{-1} at 10 m high and above. Egypt, which lies to the North West of Eritrea and has Red Sea coastline, has continued to take advantage of this wind by establishing wind farms in the region. In recognition of this potential, Eritrea has established wind farm in selected areas. For example, wind farm at Assab was already contributing 25 % of the town's electricity requirement by 2014. Clearly, Eritrea's efforts on renewable energy development are in the right direction. There is also abundant solar energy, which the country can develop and, given its small population, it can quickly become Africa's good example of green energy.

5.9 Ethiopia

Ethiopia has very little fossil-based energy reserves. In 2003 its oil and gas reserves were estimated to be about 428,000 barrels and 880 billion cubic feet respectively. These have not been exploited but exploration for possibilities of finding more of these resources are going on. The country however has significant hydro potential especially on the Blue Nile that originates from Lake Tana, flows westwards and joins the main River Nile at Khartoum, Sudan. The rules that control the use of the waters of River Nile were formulated and signed between Egypt and Britain during the period Britain colonised and ruled most upstream countries, as was discussed in Chap. 2. According to the agreement, upstream countries were not expected to use River Nile for irrigation or any other purpose that would reduce the flow of the water. Fortunately for Ethiopia, it was not bound by these rules as it was not colonised by the British. Ethiopia also has a huge geothermal energy potential estimated to be nearly 7000 MW out of which only 7 MW had already been tapped. Most of its electricity in the early 2000s was generated from hydropower facilities but from around 2005, it came up with a new energy generation plan that aimed at diversifying electricity generation. This plan included the expansion of more geothermal, wind, solar and hydro power plants. Geothermal power plants with a total installed capacity of about 1000 MW are expected to be operational by 2018 while hydro is to rise to an installed capacity of over 8000 MW when the Grand Ethiopian Renaissance Dam, with an installed capacity of about 6000 MW, will have been completed. A solar panel assembly plant was established in Addis Ababa in 2013 capable of producing nearly 20 MW/year. A wind farm has also been developed to a capacity of 171 MW and this is expected to increase to about 800 MW according to the Ethiopian Electricity power Corporation (EEPCo). One of the early wind farms in Ethiopia is shown in Fig. 5.16. Already, there are a number of solar energy installations totalling about 5 MW in use in the country. This is also expected to increase if the new energy development plan is implemented. According to the government's Master Plan Ethiopia aims at producing 30,000 MW by 2020, with much of it to be exported to Kenya, Sudan, Egypt, and West Africa. Ethiopian-Kenyan, Ethiopian-Sudan and the existing Sudan-Egypt transmission lines are expected to open the market for Ethiopian electricity to these regions and to West Africa. If, by 2020, the Ethiopian plan succeeds, it will make the country the first one to export energy in this large scale in Sub-Saharan Africa.

It should be noted that, in 2012, Ethiopia's total electricity installed capacity was only 2167 MW out of which hydro contributed 94 % while wind, geothermal and thermal generators contributed the rest. The population having access to electricity was less than 20 %. But, by 2014, all this had changed and, if the ambitious plan is successfully implemented by 2020, Ethiopia will have recorded the fastest growing energy sector in Africa. It is also expected that electricity access growth rate will match this energy expansion and, if so, electricity access level will be the highest in Sub-Saharan Africa and with its population of nearly 97 million people, this would be one of the leading good examples for Sub-Saharan Africa.

Evidently, Ethiopia has a huge renewable energy potential, which is fairly well distributed throughout its territory and this puts the country in a highly favourable position not only for national power infrastructure development but also for

Fig. 5.16 One of the early wind farms in Ethiopia

independent power producers. In addition to this, the government of Ethiopia is conspicuously supportive of energy sector development and has indeed put in place a conducive policy environment for investment in renewable energy facilities.

It is apparently clear that Northern Africa is well endowed with both fossil-based energy resources and renewable energies and it is also clear that the governments in the region are committed to positive energy development initiatives. Thus, the conducive energy policy framework should be attractive to investors. There are indeed early signs that investment in, and support for energy sector in the region is on the increase.

References

1. Arab Organization for Agricultural Development. (2012). *Statistical book* (Vol 32).
2. Brahim, F. B., Makni, J., & Bouri, S. (2013). Properties of geothermal resources in Kebilli region. *Southwestern Tunisia, Environmental Earth Sciences, 69*(2013), 885–897.
3. EIA. (2014). *Key world energy statistics from 2006 to 2013*.
4. Elamouria, M., & Ben Amara, F. (2008). Wind energy potential in Tunisia. *Renewable Energy, 33*(2008), 758–768.
5. Farouk, E. (2013). *Egyptian renewable energy activities and strategy new and renewable energy authority, Egypt*. Available on line http://www.unido.or.jp/download/NREA_Strategy_April_2013.pdf. Accessed Aug 2014.
6. Fekraoui, A. (2010). Geothermal activities in Algeria. In *Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia*, April 25–29, 2010, paper No. 0117.
7. Hermann, S., Miketa, A., & Fichaux, N. (2014). *Estimating the renewable energy potential in Africa, IRENA-KTH working paper*. Abu Dhabi: International Renewable Energy Agency.
8. Idris, M. (2000). Geothermal evaluation of thermal fluids at Helwan Springs, Egypt. In *Proceedings of the 2000 world geothermal congress, Kyushu-Tohoku, Japan*, May 28–June 10, 2000.
9. Khellaf, A, Khadri, F., & Guezzane, S. (2002). Photovoltaic option in Algeria: Current action. In: *Euro Mediterranean workshop on Euro-mediterranean renewable energies, European Commission's INCO Program*, Nicosia, Cyprus, May 18–21, 2002.
10. Lashin, A. (2013). A preliminary study on the potential of the geothermal resources around the Gulf of Suez, Egypt. *Arab Journal of Geosciences 6*, 2807–2828.
11. Lund, J. W., Freeston, D. H., & Boyd, T. L. (2011). Direct utilization of geothermal energy 2010 worldwide review. *Geothermics, 40*(2011), 159–180.
12. Mohamed, M. B. (2003). Geothermal resource development in agriculture in Kebili region, Southern Tunisia. *Geothermics, 32*, 505–511.
13. Mohamed, M. B. (2010). Geothermal Direct application and its development in Tunisia. In *Proceedings of the world geothermal congress 2010*, Bali, Indonesia, April 25–29 2010.
14. Mortensen, N. G. (2006). Wind Atlas for Egypt a national database for wind resource assessment and wind power planning. Risø National Laboratory MENAREC 3, Cairo, Egypt 12 June 2006.
15. Renewable Energy Authority of Libya (REAoL), National plan for developing The renewable energy in Libya (2013–2025) https://www.iea.org/media/workshops/Libya_RE_National_Plan.pdf. Accessed August 2014.
16. Saleh, I. (2006). Prospects of renewable energy in Libya. In R. Ramelli., O. M. Shalabiea, I., Saleh, & J. O. Stenflo (Eds.), *Proceedings of the international symposium on solar physics and solar eclipses (SPSE), Libya,* March 27–29 2006.
17. The wind power, http://www.thewindpower.net/country_africa_en.php. Accessed July 2014.

18. Trieb, F. (2005). *Concentrating solar power for the Mediterranean region, final report, DLR&BMU, Stuttgart 2005*. Also available online: http://www.dlr.de/tt/med-csp.
19. Zaher, M. A., & Ehara, S. (2009). Heat flow and geothermal resources in Egypt. *Journal of the Geothermal Research Society Japan, 31*, 155–166.
20. United Nations. (2014). UNEP Environment Questionnaire on Environment Statistics. Online: http://unstats.un.org/unsd/environment/municipalwaste.htm