

Renewable Energy Development in Algeria: Applications, Opportunities, and Challenges

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Abstract— This paper discusses the most viable renewable options for Algeria and suggests simple, but effective, engineering applications related to solar, wind, geothermal and biomass. Also included is a discussion of both the opportunities and challenges related to renewable energy development and a critical review of Algeria's controversial plans for nuclear energy and shale gas developments.

Keywords; *renewable energy; solar energy; wind energy; geothermal; biomass, policy, smart grid, nuclear, shale gas.*

I. INTRODUCTION

Serious interest in renewable energy was sparked following the Arab Oil embargo of 1973 and since then much progress has been made towards a variety of renewable energy technologies. Examples include solar, wind, hydropower, geothermal, bio fuels, ocean waves, and tides. Nowadays, this is referred to as the 'renewable energy mix', a term that indicates the need for a country to diversify its energy sources. The environmental impacts of fossil fuels (e.g. oil spills, coal mine disasters, climate change due to harmful gases) and of nuclear plants (e.g. nuclear meltdowns of Chernobyl and Fukushima) are well known. Apart from being clean, free and abundant, what is perhaps significant about renewable energy sources is that they have no political and geographical boundaries with little need for means of transport [1]. Some of these, especially solar and wind, have already achieved commercial acceptability, economic viability and compatibility with existing modes of energy generation, making them serious alternatives to traditional means. Given the central place that energy occupies in our societies especially with expected increase in human population and demand, renewable energy will likely to assume greater significance for the future of our civilisation. Germany and Japan are so confident in the potential of renewable energy that they have decided to progressively phase out their nuclear power plants. In such context, this paper aims to shed some light on the potential of renewable energy development in Algeria, to offer suggestions for effective renewable-based solutions, to highlight the technical challenges and opportunities within renewable energy such as the smart grid, along with effective economic, environmental and political considerations. The paper also discusses Algeria's plans for exploitation of its nuclear and shale gas reserves.

II. BRIEF REVIEW OF CURRENT STATUS

Luckily for Algeria there is abundance of oil and gas resources; Algeria is amongst the top five countries in the world for producing natural gas and in the top ten for oil production [2]. For a very long time now these have been the main export revenue for the country, currently accounting for more than 95% of the country's total export revenues [3]. Unfortunately, however, this has made the country heavily reliant on hydrocarbons with 94% of energy currently coming from natural gas which also represents approximately 50% of the country's GDP according to recent reports in the national papers. Latest estimates claim that about 5% of the country's electricity comes from hydropower plants while only a tiny portion of 0.5 -1% is from renewable sources of solar and wind [4]. On the contrary, other countries are already well ahead in adopting renewable energy. In Germany alone, the total share of electricity produced from renewable sources reached a staggering 20.5% in 2011, up from 6.3 % in the year 2000, and more than the 2010 contribution from gas-fired power plants [5]. Despite low solar radiation compared with other European states, Germany is the leading country in the production of solar energy in Europe. In 2012, the proportion of electricity produced from renewable sources reached 13.2 % in the USA [6]. In China, the share of renewables in the domestic energy market increased from 8.4% in 2010 to 11.4 % in 2011 [7]. Perhaps most interestingly, Japan is seriously working towards 100 % renewable energy use by 2020 [8]. Algeria's installed electrical capacity has been recently estimated at 8,000 MW with an energy demand that increases at 5% annually [9]. Unfortunately, the lack of renewable energy development in Algeria occurs despite the country's favourable geographical location which offers one of the highest solar potentials in the world. Thus, Algeria faces a real challenge between its dependence on fossil fuels and its huge potential for exploiting renewable energies. Electrical energy consumption in Algeria will rise to 83 TWhr in 2020 and up to 150 TWhr in 2030 [3]. According to the study of [4] the projections are that the reserves of oil can only cover the next 50 years while those for natural gas will only be available over the next 70 years. Luckily, in the last few years there seem to be some ambitious plans to develop

renewable energy over the period 2011-2030 by aspiring to generate 40 % of local electricity production by 2030 from solar and wind [4]. Within this plan the estimated installed capacity is 22,000 Megawatts (MW): 12,000 MW for domestic market and 10,000 MW for possible export. The initial budget is about \$60 US billion.

III. POTENTIAL AND APPLICATIONS OF RENEWABLE ENERGY

Recent reports e.g. [10] show that energy usage in Algeria is split mainly between three sectors: industrial use (24%), transport (33%), and residential and services (43%). In terms of the potential contribution of renewable energy in Algeria and possible engineering applications and solutions it is important to consider the following sources:

A. Solar Energy

The map in Figure 1 illustrates the huge solar potential in the country as well that of the Middle East and North Africa (MENA) region ($1 \text{ TW} = 10^{12}$ Watts). Algeria resides within the so called solar belt of the world. To understand the true potential of solar energy, it is estimated that 6 hours of solar power from deserts around the world can meet the annual global energy demands.

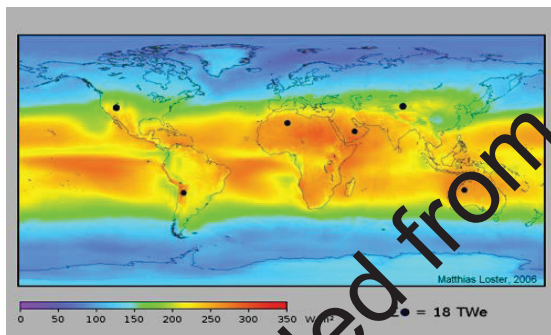


Figure 1. Hot spots of solar energy in the world (www.desertec.org)

The potential use of solar energy in Algeria may be split into two categories: solar thermal and photovoltaic (or PV). With solar thermal technologies, about 169,440 TWhr/year may be harnessed [11]. This is equivalent to 5000 times the current energy usage in the country. With such potential one wonders about simple solutions that can be used to put this energy to good use. Solar thermal technology can be used for the provision of heating or for electricity generation. For domestic use, Algerian houses may be fitted with solar thermal tubes to exploit solar radiation in heating water using either flat plate solar collectors or the more advanced types with evacuated tubes. Figure 2 illustrates such technology which can easily be installed on Algerian homes.

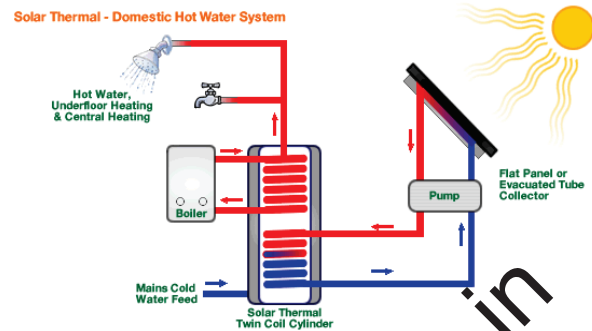


Figure 2. Domestic use of solar thermal for hot water [12].

For electricity generation, it is possible to use concentrating solar technology to gather and focus solar thermal energy in order to drive industrial steam and gas turbine plants that in turn drive electric generators. On large MW scale, solar farms may be built in the vast Algerian desert using for instance the very successful concept of solar towers where solar radiation is focused onto the top of a tower from a large number of concentrating mirrors (Figure 3). Thermal energy from concentrating solar technology could easily be used to provide hot water. Figure 3 illustrates some of the concepts which are already used in places around the world, e.g. the solar tower has been successfully operational in Spain.

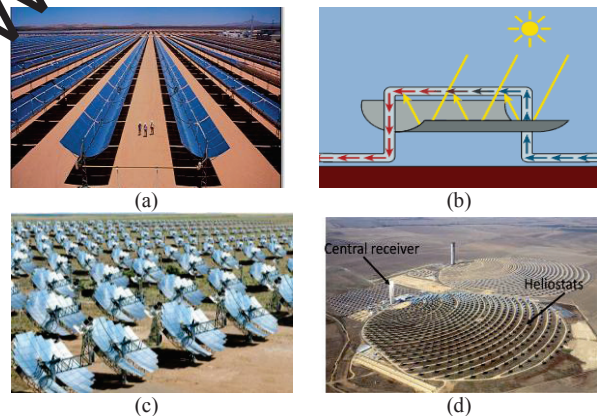


Figure 3. Applications of solar thermal for electricity and heating: (a) solar concentrator for electricity, (b) solar concentrator for hot water, (c) solar farm using Stirling engines, (d) solar towers with steam/gas turbines.

With solar photovoltaic, solar radiation is directly converted into electricity. Algeria boasts a potential of 13.9 TWhr/year for PV [13]. Solar PV panels may be installed in Algeria for different applications. From panels that can be attached to the roofs of people's houses, to larger capacity panels that can be used to provide the electricity needs of schools, hospitals, supermarkets, to the industrial MW large scale using solar farms. PV panels are widely used around the world and are now considered to be a well developed, mature technology. The electricity from PV panels can be used to provide power for isolated communities, e.g. to pump water or to run solar refrigerators that preserve

medicine in such areas. Solar panels may also be installed on large transport trucks to provide food refrigeration.

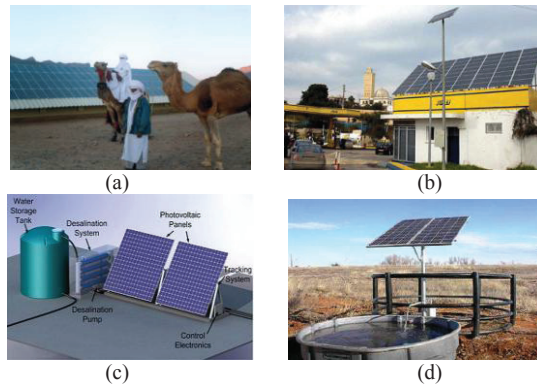


Figure 4. Some possible applications of solar energy in Algeria: (a) rural/desert, (b) stations, (c) water desalinations, (d) water pumping.

A major industrial application is using solar energy for desalination plants to provide fresh drinking water which is not an abundant source in Algeria. Some of the proposed applications are illustrated in Figure 4. As an encouraging example of Algeria's move towards adaptation of solar energy, a large hybrid power plant in Hassi R'Mel has been installed and has become operational since 2011. The hybrid plant combines solar energy and natural gas to provide a total capacity of 150 MW of which 25 MW comes directly from concentrating solar arrays [10]. Hybrid plant solutions like this represent a general trend followed in many countries, such as China, to integrate renewables progressively into the energy mix. Other exciting future projects for Algeria include the planned Photovoltaic power station in Ghardaja, South of the country and a PV solar farm in Rouiba, near the capital Algiers. The key challenges of solar energy include:

(i) Efficiency of converting solar energy into electricity either directly (PV) or through solar thermal (using engines) like concentrating troughs or solar towers

(ii) Intermittency: this is due to the unavailability of solar energy all the time e.g. overnight, variation in time of solar intensity, and panel orientation. This implies the need for 'energy storage' e.g. utilising batteries, hydrogen based storage, or the promising thermal storage using phase change materials.

(iii) Economic viability: Renewable energy generation cost money and so projects must generate return on investment over reasonable periods of time, currently on the scale of few years. Renewable energy projects invariably require a huge setup costs. To cover this requirement, both national and international grants should be sought after. Two other issues related to the cost are the actual energy output and the generation life of installed solar systems.

B. Wind Energy

Results of some recent investigations regarding the potential of wind energy in Algeria show that this is the second most important renewable resource [1, 3, 4]. The power contained in the wind is a very strong function of mean wind velocity such that the power available to extract increases eight folds with a doubling of wind velocity at a site. A fundamental property of wind speed is that it increases with height through the atmospheric boundary layer. The wind turbines, take this available energy from the wind using their blades before finally converting the mechanical energy into electricity via electrical generator. The actual energy extracted by a wind turbine has inefficiencies related to the mechanical and electrical conversion processes. There have been some research studies of the resource assessment of the wind potential in Algeria, as illustrated in Figure 5.

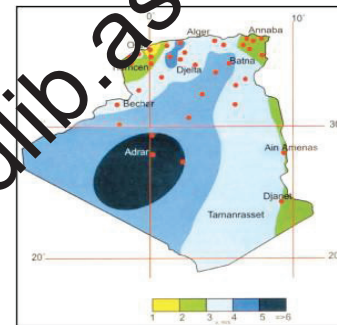


Figure 5. Recent wind resource assessment in Algeria [3].

It is interesting to see from Figure 5 that the highest wind speeds seem to be focused in the South west region particularly the region of Adrar. This is why Algeria expects to have its first wind farm in Adrar operational between 2014 and 2015, generating around 10 MW. There are also plans to install two wind farms of 20 MW generating capacity each. Probably contrary to intuition, it seems that the coastal regions of the country offer far less potential than the southern regions. A possible explanation is that the Mediterranean Sea is quite a sheltered region from the open vast regions of the ocean, whereas the southern west region is facing the Atlantic Ocean to the west. More studies are, however, needed for a full assessment of the wind resource. Wind turbine technology is now a well established technology and its adaptation in Algeria should be accelerated using both onshore and offshore wind turbines. Examples of application areas for wind energy systems might involve the use of vertical-axis wind turbines at schools, hospitals, airports and large stores. In fact, wind turbines can be raised wherever there is enough blowing wind; in isolated rural areas that are cut off from the national grid, along highways and on top of large buildings. Coastal cities could easily benefit from offshore wind farms that could be connected to the main grid using subsea cables. Wind turbines can provide site specific energy requirements like at airports and rural locations, or can be connected to the grid. Figure 6 illustrates some of these suggestions.

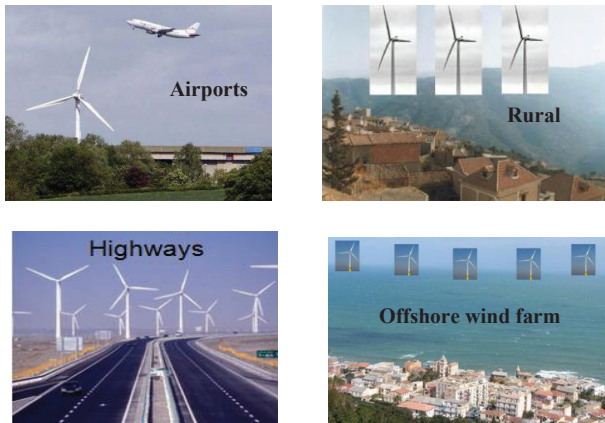


Figure 6. Possible applications of wind energy in Algeria.

Apart from the above slightly ‘large scale’ applications, it is in fact possible for any individual person to build and install their own wind turbine to power their home. This is becoming more of a common practice in countries like UK and Denmark. Just like solar energy, developers and investors can sell their wind power to the national grid, thereby earning financially. Some of the challenges of wind energy development include:

(i) Intermittency: just like solar power, wind energy is weather dependent so power is not available at all times. Thus, some form of energy storage should be available, e.g. batteries that store excess power and use it when required to provide a continuous power supply to users.

(ii) Aesthetic: some people find wind turbines unattractive to look at and especially near areas of outstanding natural beauty there is often local opposition to wind turbine constructions.

(iii) Noise: wind turbines can be quite noisy especially to nearby residents.

(iv) Grid integration: intermittent electrical power from wind turbines can cause difficulties when attempting to make a connection to the grid. Inverters must be available and well designed to deal with power variations at the grid interface

(v) Bird strike: there is evidence that many birds die due to being struck by fast rotating blades. Opposition from ecologists is therefore expected.

C. Geothermal Energy

It is possible to talk of two main types of geothermal technology: 1) hydrothermal systems based on hot springs originating from thermal reservoirs few kilometers beneath the earth, and 2) ground source heat pumps (GSHPs) utilising the first few meters underneath the earth surface as a thermal reservoir.

In terms of hydrothermal systems, recent estimates have counted more than 200 hot springs in a number of regions around the country, the most known are located in Guelma,

Khenchla, Biskra and Setif [4]. So far these hot springs, or Hammamat, have been used exclusively for physical therapy and pleasure. Their commercial viability has yet to be fully explored. These geothermal resources have both low grade (low temperature) and high grade (high temperature) heat with more than a third having temperatures above 45° C [4]. Three feasible applications utilising these hot springs are suggested to provide additional useful energy:

(i) Simply use the hot springs as a means of providing hot water to nearby residents or large commercial buildings (i.e. district heating). This should only require well-insulated pipe networks and duty pumps. Electrical energy to operate the pumps could easily come from solar PV panels.

(ii) Some locations have high water temperatures, e.g. at Hammam El Maskhoutin in Guelma (98° C) and another in Biskra (118° C) [3]. These can be used to provide hot steam, at specific pressures, as required by process industries such as paper mills or other industrial drying processes.

(iii) The third option involves superheating the existing hot water, i.e. raising its temperature considerably beyond boiling point to generate ‘superheated steam’ that can be used in steam engines to generate both electricity and heat. The superheating process can easily be achieved using solar energy for instance via concentrating parabolic troughs. This particular scheme is illustrated in Figure 7.

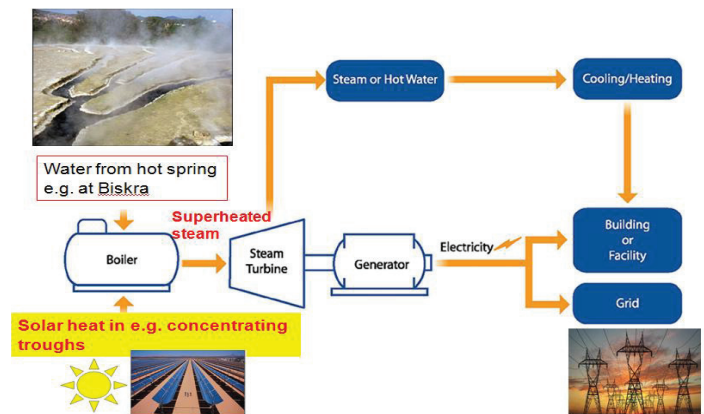


Figure 7. A scheme to use hot springs to generate electricity and heat.

The use of hydrothermal systems is in principle feasible as long as technology is available to drill deep holes (wells) to go through hot rock formations, thereby extracting hot brines. In particular, the future of this technology will most likely rely on industrially simulating production wells at deep levels, a practice referred to as Enhanced Geothermal Systems (EGS).

The second technology of ground source heat pump is a rapidly expanding, effective renewable solution that should

be adapted quickly in Algeria. The idea of GSHP is quite simple: to use the constant temperature of the ground ($\sim 15^{\circ}\text{C}$) few meters below the surface to provide heating in winter and cooling in the summer. Figure 8 the working principles of this technology. It involves digging a network of tubes to depths of 10-15 m and using refrigerants that can absorb and release heat energy rapidly.

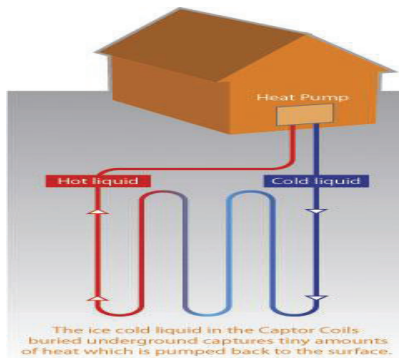


Figure 8. A general GSHP scheme for domestic heating.

By reference to Figure 8, when the system is used for heating a cold liquid (e.g. water or water with a refrigerant) flows in the tubing (or coils) collecting heat from the surrounding hotter ground and delivering this heat back to the building thereby providing the heating effect. The reverse is achieved when the system is used for cooling where this time the flowing liquid extracts heat from the house and dumps it to the ground making the house cooler. As the GSHP system is buried under ground it offers a non-intrusive approach of useful energy transfer. Even in a country like the UK where land space is at a premium many residents have opted to install such systems under their gardens to provide floor heating. If enough land is not available to install the system then vertical rather than horizontal, coil system can be used (as in Figure 8).

D. Biomass Energy

Biomass is a general term for all types of animal and plant material. There are many sources that contribute to the biomass energy including municipal solid waste, animal and industrial residues, agricultural and forestry crops and residues, and even sewage. These materials can be burned or digested to produce useful energy in the forms of heat and electricity. A very common example is burning of wood (the fuel) for heating purposes; humans can make use of such biomass energy as long as enough trees are being planted (i.e. there exists a sustainable source). Of course, such trees get their energy from the Sun for the photosynthesis process to take place.

Biomass material can be taken through a gasification process to produce gases or a pyrolysis process to obtain bio liquids. The gases and liquids can then be used as fuel to fire electrical power plants. Because Algeria has large areas of unused land it is possible to grow wheat, corn, soybeans and

sugarcane to create biofuels e.g. in the form of ethanol and biodiesel. As these plants can be grown over land not used for growing food crops, there is minimum impact on food production and prices, whilst producing biofuel that can be sold. Therefore, conflicts over land-use with food production should not prevent Algeria from exploring biomass for power generation. Policies and approaches to land-use management should reduce tensions further. Biodiesels have been used on existing modes of transport such as cars with minimum modifications to the engine. Enterprise Holdings has more than 70% of its airport shuttle busses operate on biodiesel [14]. In 2006, an Algerian biotech company, Nakheel, announced plans to produce biomethanol as a transport fuel, using non-edible waste fruits from the large date industry in the country [15]. This initiative was the first in the Arab world, driven by the fact that 20% of all produced date is not suitable for consumption, thus providing substantial amounts of biomass. However, it has not been possible to verify whether this initiative remains operational or not. Municipal waste can be used to create landfill gas which is collected and burned in large combustion engines to produce electricity. Even unwanted materials like recycled vegetable oil and grease from restaurants may be used to make biofuels. Miscanthus, a tall grass that can grow to heights of more than 3.5 m in one growing season [16] has a rapid growth rate, high yield per acre, and low mineral content, making it an excellent candidate for biofuels. It grows well on barren land, and so does not compete for land used for food crops. Last but not least, algae are a promising source for biofuel production and can naturally grow in many aquatic environments. Algae can also be harvested in photo-bioreactors, or in large scale nurseries. It is estimated that algae may possess up to 40% of its weight as oil.

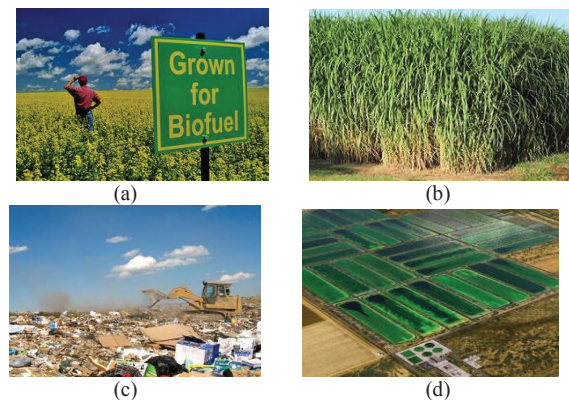


Figure 9. Sources of biomass energy: (a) Corn, (b) Miscanthus, (c) industrial waste, (d) Algae

Despite all these developments around the world there currently exists no known operational biomass plant in Algeria. Clearly with such a wide variety of ways to extract energy the Algerian government should sponsor some of these ideas to diversity its own energy mix.

IV. DISCUSSING CHALLENGES AND OPPORTUNITIES

If Algeria is to produce large amounts of renewable energies an immediate challenge is that of integration of these technologies into the existing national grid. All commercial large scale solar or wind farms will have to be integrated so that electricity is fed directly to the grid. This might mean an upgrade of the existing electrical network not only to deal with potentially increased capacity but also to respond to the challenges posed by renewable energies such as their intermittency. For instance, electrical devices such as inverters must be used along with efficient controls (via advanced 'power electronics') at the grid interface.

Renewable energies have naturally led to the idea of the 'smart grid' where, in contrast to the traditional model of a centralised power station feeding consumers, individuals can now be both consumers and producers of electricity. The smart grid system may be represented as in Figure 10. One of the main functions envisioned for future smart grids is to respond to electrical power disturbances through a self healing process that minimises disruption of electricity supply until the problem is fixed [17]. This is crucial since the Algerian electrical network still experiences, from time to time, major blackouts especially during periods of extreme weather. This often leaves consumers without electricity for hours and days, causing frustrations and personal economic loss. Clearly, electrical failures cause financial losses to any country; in the US it is estimated that its economy suffers losses between \$80 billion and \$188 billion per year as a direct consequence of electrical failures [17]. Algeria should be ready to invest whatever is necessary to ensure a successful transition to smart grids that integrate the various renewable energies. Already China has spent \$7.3 billion on its own smart grid to conserve power, maintain energy supplies and reduce its greenhouse emissions [17]. It is worth noting that other European countries, South Korea, and Brazil are doing the same [17].

Figure 10. A system of 'smart grid' involving conventional and renewable energy options [17].

Currently there is much concern of how a smart grid should operate in a way that energy usage is controlled so that unnecessary energy consumptions are avoided. In

addition, the scheme considers the possibility to allow individuals to sell their renewable energy to the grid efficiently and with minimum side effects on the electrical grid performance. Clearly, energy storage is a huge issue with renewable energy so methods of storage should be made available, whether imported or developed locally. It is possible to start using batteries to store excess energy and use it when demand is high. Excess solar, wind, or geothermal energy can be used during an electrolysis process to produce hydrogen from water. This hydrogen, produced with minimum CO₂, can be stored in hydrogen tanks and used for electricity generation in fuel cells. Another method uses phase change materials (PCMs) that change their state from solid to liquid when absorbing excess energy, and re-phase to solid state when releasing energy.

Renewable energy technologies offer many opportunities for Algeria in a number of ways. For a start, thousands of jobs for young Algerian scientists and engineers (especially recent university graduates) will be created in a number of renewable sectors instead of useless occupations like security based jobs. As an example, commercial development of solar farms in the South will enable displacement of the workforce towards more isolated regions thus supporting regional economic development. In turn, this would enrich local economies and develop the South further. Valuable technical and project management skills will be acquired by a young enthusiastic Algerian workforce. These could be provided by national research centres or international expertise to establish technical independence. Algeria does not want to be in similar position to that of oil and gas where despite the country having so much oil and gas we have always relied on foreign skills for extraction and processing.

Given the huge potential of renewable energies in Algeria serious consideration by the government towards its development would encourage international interest and collaboration, thus funding for projects would be secured. It should be appreciated that renewable projects require large sums of capital to start up. Renewable energy is a multidisciplinary science so there is a great opportunity to bring together Algerian scientists of various disciplines to capitalise on their skills. Algeria currently enjoys a lot of income from exportation of oil and gas and so it is imperative that part of this capital should be used to accelerate a parallel development in renewable energy. Otherwise, the country would miss the current wave of developments and may unnecessarily pay very dearly in the future. Amongst the opportunities is to open the door of investment for Algeria's private sector and young enthusiastic entrepreneurs instead of everything being state owned and controlled. An important thing is to create public awareness of renewable energies especially at schools and universities through summer schools, technical workshops, presentations, and even specialised degrees at high education institutions. It must be realised that investment in renewable technology would give Algerian scientists and inventors the opportunity to develop patents for renewable systems. Currently, Japan alone holds about 55% of the world's

patents on renewable energy concepts [8]. As in other countries, the government must introduce well measured and encouraging energy policies like the so called Feed In Tariffs (FiT) used in the UK which give a certain amount of money for every kW of renewable energy generated by companies and individuals whether it is electricity or heat. Amongst policies, Algeria should start placing strict obligations on large firms and public buildings to encourage them to undertake energy audit exercises to show that they use energy wisely. It is suggested in passing that Algeria can look into and learn lessons from Japan's model that is being rigorously followed to achieve 100% renewable energy by 2020 [8]. This is based on three main indicators: strong public opinion towards renewable energy, high level technology, and favourable energy policies. Alternatively, Algeria can collaborate with a number of European countries especially Germany, UK, Denmark, and Spain.

V. CONTROVERSIAL PLANS: NUCLEAR ENERGY AND SHALE GAS DEVELOPMENTS IN ALGERIA

Recent announcements indicate some 'controversial' plans to build nuclear power plants for electricity generation in addition to possible exploitation of Algeria's shale gas reserves. Despite the importance of such developments for Algeria, only a limited discussion of these plans and their potential effects on the energy sector in the country is included in this paper.

Starting with nuclear energy, there currently exist no nuclear power plants in Algeria. It was back in 2008 that Algeria first announced an ambitious plan to build its first ever nuclear power plant for electricity generation by the year 2020 [18]. Reports claim that Algeria enjoys sufficient uranium reserves to enable two nuclear power plants with a capacity of 1000 MW each to generate clean and cheap electricity for 60 years [18]. Algeria's uranium deposits are estimated at 26,000 tones and are located in the Southern Saharan desert [19]. The country has already established a number of nuclear engineering research centres as well as the recent Nuclear Energy Institute (2011) and the Nuclear Security Centre (2012), all with the aim of training future engineers and technicians who will be entrusted with the operation and safety of the nuclear power plants. Furthermore, a basic infrastructure of two research nuclear reactors, Nur (1MW) and Es-salam (15MW), already exists in the country from the earlier nuclear research work of the 1970s and 90s. All this is an indication that Algeria is actually in a good position to diversify its energy needs further through nuclear power. One of the proposed uses of nuclear-based electricity is for producing much needed fresh drinking water via seawater desalination [20]. In principle, international expertise can be used to help construct Algeria's power plants and would allow efficient production of electricity; nuclear energy is so efficient that countries like France in particular intend to continue to use it for many years to come. Some skeptics, however, believe that security fears related to unrest in North Africa, such as the terrorist attack on the Tiganourine gas facility at In Amanas in

January 2013, may delay such international collaboration [21] or give international companies more negotiating powers for larger stakes in energy extraction projects. Related to this is the issue of corruption that surfaces from time to time, sometimes even involving high profile officials either within Algeria's two national companies Sonatrach and Sonalgaz, or within international energy firms operating in Algeria. As a country that has suffered disastrous consequences of nuclear tests in its desert in the 1960s as undertaken by the French there is a strong moral issue against nuclear plant proliferation. Recent disasters such as Fukushima in Japan, is a stark reminder that despite a low percentage of accidents, nuclear meltdown may have irrecoverable effects. The Fukushima accident in particular calls for major revisions on existing safety requirements for nuclear power plants, and a re-assessment of seismic acceptance criteria [9]. Also, the question remains as to what to do with decommissioning of nuclear plants once they have reached their working life and how to dispose of dangerous nuclear waste. There seems to be little investigation or concern about public opinion at least for those who would reside near a power station and who could, for good reasons, oppose the construction of such nuclear stations. Perhaps a stronger argument against considering the nuclear energy option is the fact that Algeria clearly have significant clean, free solar and wind potential that can sustain its power needs and this is where serious money should be spent.

In terms of shale gas, this is seen by many around the globe as the new 'energy bullet', partly due to its vast availability. Shale gas is essentially natural methane and oil which is trapped in tiny pockets in shale formations and is thus a fossil fuel [22]. It is extracted by the process of hydraulic fracturing, or fracking, which involves drilling into shale gas pockets and pumping liquid down at very high pressures to break up the highly impermeable shale formations and release the stored oil and methane gas [22]. In June 2013, the US Department of Energy said that Algeria's shale gas resources are estimated at 19,800 billion cubic meters [23], sufficient to make the country a significant contributor to the European market for many years [24]. With these estimates, Algeria ranks third behind China and Argentina [23]. Algeria is the first African country to contemplate research plans aimed at exploring its vast reserves of shale gas. In contrast to clean nuclear energy, the argument for or against shale gas exploitation rests on its ability to slow or accelerate climate change. It also rests on the capital costs not yet very well understood for the exploration of an unconventional source of fuel. Supporters of shale gas development claim that burning of shale gas emits half as much carbon dioxide as the same amount of coal, currently used by many countries, especially China, for electricity production (coal also produces more soot, radioactive ash, sulphur dioxide, and oxides of nitrogen). According to some reports, since the USA embraced shale gas the emissions due to carbon dioxide have fallen, especially beyond 2005 [22]. While this is true, a hotly debated issue at the moment is the amount of methane, a potent greenhouse gas, that can escape at the surface to the

atmosphere during fracking; this is not usually taken into account when comparing shale gas emissions with that of coal. The main issue with methane escaping into the atmosphere is that it is 25-30 times more powerful than carbon dioxide. Nonetheless, one of the arguments supporting an economy based on hydrocarbons, in the medium term at least, is the fact that renewable technologies are not yet ready to fully substitute conventional fuel based options. In this context, shale gas is seen as the one option that would bridge this gap until a full renewable energy conversion is achieved [22]. Despite its vast resources of hydrocarbons, it has been difficult for Algeria to attract foreign investment from international oil companies into the country over previous licensing rounds of 2008-2010 [24]. One of the potential conflicts of interest would be the desire of foreign investors to secure improved deals for exploring unconventional sources such as shale [24], because not all types of shale are easy to extract [22], for examples some types of shale are harder to break with feasible pressures found with existing fracking methods. For Algeria, field assessments are thus required to identify the type of shale in the country in order to decide how best to explore it.

While Algeria should reasonably think of exploiting all its shale gas reserves, a major issue is the required amounts of water (and other chemicals) that must be pumped at high pressure to enable extraction of gas. Algeria is already very short on water due to low precipitation. Opponents to this scheme are also worried that toxic chemicals from fracking can reach and pollute water reservoirs underground. Although studies have so far shown low risk levels of underground water being contaminated by toxic chemical, appreciable amounts of methane in water wells nearby exploratory sites have been found [22]. Apart from the huge costs that must be justified by careful analysis, fracking might cause seismic problems. In 2011 for instance, tremors of magnitude 1.5 to 2.3 were felt near an exploratory site near Blackpool, UK; these were directly linked to fracking activities [22]. One might argue, however, that with careful engineering problems associated with fracking can be overcome making the whole process safe. Extraction of shale gas in the USA was responsible for transforming the energy landscape in the country as shale gas alone accounted for 20% of US natural gas production in 2010. It is argued that this shale gas success in the US could be replicated in Algeria and elsewhere, but of course more investigations must be performed about extraction options and thus costs before such a major decision is made. The message is clear: success in the US does not necessarily mean success elsewhere as shale gas exploration is a complex issue that is related to the type of shale, how much gas it has, how difficult it is to extract the gas, the available incentives in the country, and so on. Some critics also fear that Algeria is simply trying to follow the US example without well defined plans, at a time when some European countries like France and Germany have blocked any plans to exploit shale gas in their territories. One central fact to remember is that it has taken the US 25-30 years to bring its shale gas sector to where it is now [22], so there should be no delusions on the

time and effort required to set up a successful exploration program. One of course would argue that with advanced engineering concepts such as ‘horizontal drilling’ introduced over the last five years [22] and international expertise, Algeria should be able to start using its shale gas over a much shorter period. Energy policy incentives such as FiT and subsidies should be introduced to encourage those investors interested in fracking. Even if Algeria chooses to go ahead with its shale gas exploration, one thing is certain: this remains a temporary solution to the energy problem and shale gas will run out one day. This again favours the argument for accelerated renewable energy developments. From Figure 11, one of the shale basins is close to existing power stations in the In Aminas industrial complex so, by happy coincidence, it would be relatively straightforward to transport the fracked gas into the power stations to produce electricity. However, the basin in Tindouf might present difficulties regarding the transportation and new infrastructure needed to extract the gas and oil, thereby potentially increasing the costs. But optimists argue that because the technology of fracking is relatively mature, productivity would be high such that shale gas prices might even fall below natural gas currently being extracted.

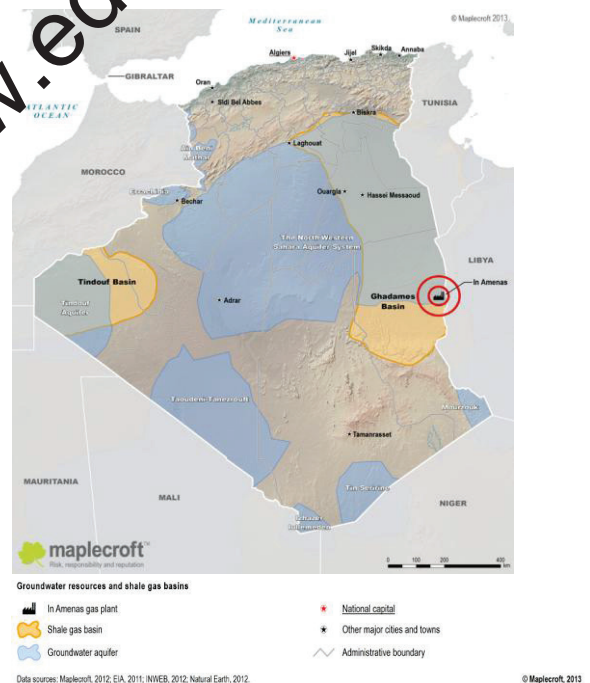


Figure 11. Map showing potential sites for shale gas in Algeria [24].

VI. CONCLUSIONS

This paper has highlighted the significant potential of renewable energy in Algeria in particular solar and wind sources and to a lesser extent other forms such as geothermal and biomass. These technologies offer a large number of simple, feasible, and economically viable engineering

applications that can be implemented both in the short and long terms. The applications are mainly based on solar and wind both of which are well established technologies. However, the potential from geothermal and biomass should not be underestimated; in fact it seems Algeria has yet to seriously look into the potential of the last two options. The applications whether to generate renewable heat energy or electricity can greatly enhance the quality of life in Algeria, create jobs, develop key technical skills, and most importantly reduce the country's dependence on oil and gas while meeting our obligations of reduced greenhouse effects and that of global warming. In the short to medium terms, increased renewable energy production will enable better management of available fuel based reserves. Hybrid power plants seem to be a major solution for the progressive use of renewable energies. There is no doubt that Algeria is well placed to continue to be a major player in the lucrative market of renewable energies. However, transition to renewable energy will need to be accelerated. It is hoped there will be more political will and favourable energy policies (subsidies and FiTs) to achieve a giant stride towards embracing the renewable energy age. The paper has highlighted the advantages and disadvantages of the 'controversial' plans for nuclear power plants and extraction of shale gas. In parallel with renewable energy development plans, shale gas and nuclear power programs must be carefully studied instead of being rushed into, particularly when considering the blurred picture of environmental and economic costs, and the conflict these may create with Algeria's move towards a fully renewable energy market.

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