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Albian drilling's and its hydropower potential in Algeria: Study and exploitation

Albian y su potencial hidroeléctrico en Argelia. Estudio y explotación

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ABSTRACT

The Continental intercalary groundwater is highly sought for its water as resources hugely mobilized in Northern Sahara. A very high flow rate and output pressure characterizes this groundwater. It amounts from 50 to 400 l.s^{-1} for the flow, and from 5 to 40 bar for pressure. A survey of the Northern Sahara Aquifer System was essential to prove the existence of this potential. This energy appears into the artesian form, which remains very considerable for a very long time in most borehole. We have realized that this energy is immense, as well as the expanded volume of the groundwater, and the importance of its use in agriculture. Unfortunately, this potential remains untapped to this day and the energy of this water is completely neglected. Several turbo generator and/or inverted pump (PATs) integration tests were undergone. The new concept of reflection with respect to the environment and sustainable development has led us to structure our work towards the extension of this potential in order to extract the exploitable energy.

Keywords: Albian, Continental Intercalary, borehole, Northern Sahara, Turbo generator.

RESUMEN

El agua subterránea intercalar continental es muy buscada para sus aguas como recursos movilizados en el Sahara del Norte. Un caudal muy alto y una presión de salida caracterizan esta agua subterránea, la cual, es de 50 a 400 l.s^{-1} para el flujo, y de 5 a 40 bar para la presión. Una encuesta del Sistema Acuífero del Sahara Septentrional fue esencial para probar la existencia de este potencial. Esta energía aparece en la forma artesiana, la cual permanece considerablemente durante mucho tiempo en la mayoría del pozo.. Nos hemos dado cuenta de que esta energía es inmensa, así como el volumen expandido de las aguas subterráneas, y la importancia de su uso en la agricultura. Desafortunadamente, este potencial permanece sin explotar hasta el día de hoy y la energía de esta agua es completamente desperdiciada. Se realizaron varios ensayos de integración de turbo-generador y / o de bomba invertida (PATs). El nuevo concepto de reflexión con respecto al medio ambiente y el desarrollo sostenible nos ha llevado a estructurar nuestro trabajo para extraer la energía explotable.

Palabras clave: Albiano, Acuífero Continental Intercalar, Perforación, Sahara del Norte, Turbo generador.

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Introduction

Groundwater can be found in many forms. They may be in the form of free groundwater "aquifers", where the water level in the borehole corresponds to that of groundwater. Some groundwater are found confined deep down impermeable layers and thus contain under pressure of water. At the end of the 19th Century, the emergence of borehole in the Northern Sahara Aquifer System (NSAS) was intended to give new impetus to the development of the Sahara (PNUD-UNESCO, 1972).

Qualified in 1945 as "the greatest hydraulic system of the Sahara" by Savornin (1947) in Dubost (2002), and studied extensively in Dubost (2002). Covering an area of 600 000 km^2 and containing 50 000 billion m^3 of water in reserve (Hellal & Ourihane, 2004). It was presented in the sixties (Cornet, 1961) as the final solution to aridity and underdevelopment of the region (Figure 1).

Taking cue from the study by BURGEAP in 1963 (FUEL DIRECTION in France), a more quantified approach of hydraulic phenomena was reached. Other studies have been initiated by several authors on the use of geothermal energy of this water (Benhammou & Draoui, 2012; Hellel, Bellache, & Chenak, 2006; Salima Ouali *et al.*, 2011; S Ouali, Khellaf, & Baddari, 2006; Saibi, 2009; Zouakh, Ferhane, & Bounouni, 2016), but no studies on the use of the hydraulic energy of the NSAS water has reached any results to this date.

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The water that comes out of this source is too demanding of energy. It requires an engine running at a minimum of 30 Kilowatt to allow direct use. Yet the energy released from the gushing water borehole is not to be underestimated especially since we already lose it out at the start.

The collection of information on the Continental Intercalary, the study of the behavior of water at the outlet of borehole and quantification of the borehole water energy potential, are milestones data required for proper understanding of the situation.

Loss and unused energy from the water that came at a high pressure are the consequences of the use of water cooling tower. After the incorporation of a turbine engine in the circuit, the use of the smallest available energy has made the installation profitable (Pugliese, De Paola, Fontana, Giugni, & Marini, 2016).

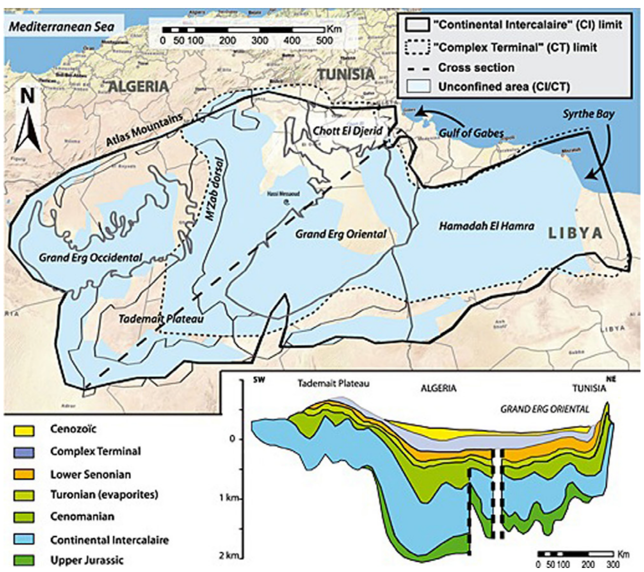

Figure 1. Distribution of Continental Intercalary groundwater.
Source: Gonçalvès, Petersen, Deschamps, Hamelin, & Baba-Sy (2013)

The Continental Intercalary groundwater

The water quality of the Continental Intercalary, according to CDARS (1999a), varied between good (total mineralization <1,5 g.l^{-1}) to very good (<0,5 g.l^{-1}) on its outcrop zones, and was saltier near the sector of In Salah and relatively good in Ghardaia, Ouargla and El Oued (<2,5 g.l^{-1}) (Table 1). This increased salinity is associated with increasing temperature, which exceeds 50°C for depths over 1500 m (Hellal & Ourihane, 2004; OSS, 2003).

The groundwater of the Northern Sahara Aquifer System (NSAS) were considered as non-renewable (CDARS, 1999a, 1999b; Cornet, 1961; Dubost, 2002; Hellal & Ourihane, 2004). A recent study (Gonçalvès *et al.*, 2013) showed that rainwater and runoff bring to the system an average of 1,4 km^3 per year, or about 2 mm per year to the resource surface of the groundwater.

Table 1. General data on the groundwater of the Continental Intercalary in Algeria

Characteristics	Value
Area (km^2)	600 000
Total Thickness (m)	50 à 1 000
Depth (m)	60 à 2 400
Roof depth (m)	20 à 2 000
Flow (l.s^{-1})	50 à 400
Transmissivity (10^{-3} m^2.s^{-1})	10 à 30
Storage coefficient (10^{-4})	6 à 1 200
Average supply (Hm^3.an^{-1})	270
Calculated theoretical reserve (m^3)	35 000 × 109
Temperature (°C)	25 à 70
Salinity (g.l^{-1})	0,5 à 6

Source: Hellal and Ourihane (2004)

The first application of geothermal energy from the Continental Intercalary groundwater was conducted in 1990 for heating greenhouses in southern Algeria (Saibi, 2009).

The exploitation of geothermal energy for greenhouses heating is too modest compared to the great potential geothermal resources in southern Algeria (Salima Ouali *et al.*, 2011).

In Algeria, aquaculture is still in its beginning. Some projects of fish farming have been promising in South Algeria with use of the Continental Intercalary water (Zouakh *et al.*, 2016).

The exploitation of the Continental Intercalary groundwater almost exclusively goes to agricultural use with nearly 1,95 billion cubic meters. The consumption of drinking water represents less than 10 % of the global exploitation according to (Khadraoui, 2006).

Continental Intercalary model as conducted by the PDGDRS's study has long established several simulations of various operating assumptions of the Continental Intercalary groundwater. We have recapped the report of the CDARS (1999b), to show the necessary elements, noticeably, the persistence of artesian flow for a longue time period in some areas of the Northern Sahara (up to year 2038).

State of the borehole

An inventory of all water points of the Northern Sahara and evaluation of the collected flows were completed by ANRH (National Agency of Hydraulic Resources). The results of this survey are presented in the Table 2.

Table 2. Water use and state of the Continental Intercalary borehole

Region	Exploited borehole			Non exploited borehole		Total
	Artesi-an	Pumped	Total	Abandoned	Recapped	
Ouargla	15	9	24	3	1	28
El Oued	11	-	11	1	3	15
Ghardaîa	25	51	76	2	11	89
Touggourt	1	4	5	1	1	7
In Salah	17	64	81	29	10	120
Illizi	29	10	39	14	4	57
Adrar	-	442	442	90	2	534
Gaci Touil	7	-	7	2	-	9

Source: CDARS (1999a)

Borehole's potential

Choice of borehole

The study of the Albian energy is focused on a newly constructed borehole, which showed no major problems affecting its production (Djamaa in El Oued Wilaya). The water of this borehole arrives to station head at a pressure of 18.10^5 Pa, a temperature of 50 °C and a flow of 100 l.s^{-1}. The borehole includes a water cooling tower by 16 meters high, including a hot air exhaust fan of 5 m diameter rotating by a motor of 30 kW. The electricity is routed to the borehole from conventional distribution network (Figure 2).

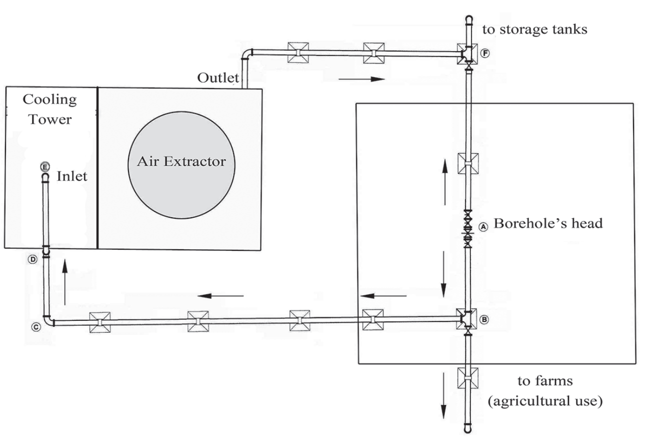

Figure 2. General diagram of the borehole.
Source: Authors

Study of energy potential of borehole

The exploitable potential Pexp represents the hydraulic power available. The following formula is derived from the basic equation of power.

$$P_{\exp} = P_r \cdot Q_t \tag{1}$$

With Qt (m^3.s^{-1}) the flow rate entering the turbine, and Pr (Pa) the useful pressure.

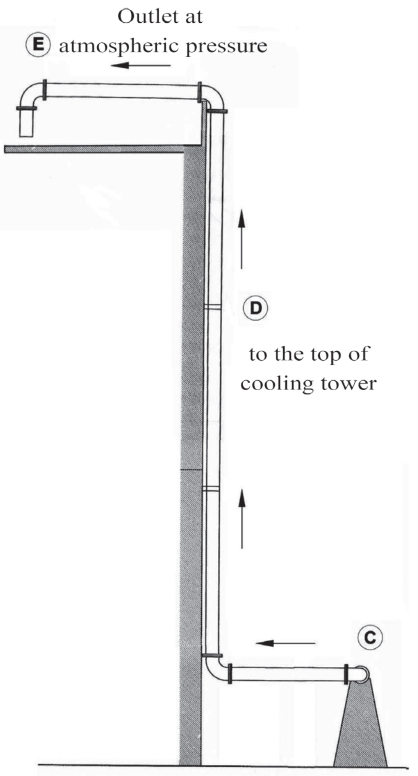

Figure 3. Leading connection- seen from the back.
Source: Authors

The useful exploitable pressure is the one at the upstream output of the water cooling tower. This pressure will be calculated according to Equation (2) of Bernoulli, taking into account all existing load losses. We get a working pressure of 16.10^5 Pa (allowing, after calculation, a total pressure loss amounting to 2.10^5 Pa).

$$\begin{aligned}&\left(P_A/\rho\cdot g\right)+Z_A+\left(v_A^2/2\cdot g\right)=\\&\left(P_E/\rho\cdot g\right)+Z_E+\left(v_E^2/2\cdot g\right)+\Delta H_{A-E}\end{aligned} \tag{2}$$

With ZA the reference level, ZE the Coast point "E" in relation to the reference, VA equals VE, PA is 18.10^5 Pa and DHA-E which is 1,4 m representing the total pressure loss between "A" and "E" (Figure 2 and Figure 3).

Flow rate entering the turbine is the amount of water arriving at the inlet of the turbine (the exit of water on upstream cooler). In our case, it is about 100 l.s^{-1}. The different cases we can encounter in the field are presented in Table 3.

A Hydraulic power amounting to 50 kW is obtained from a borehole of low potential, which is the power required to run a water cooling tower, to lower the temperature of the water from 70 to 35 °C. Whatever the characteristics of available borehole, they are able to provide a significant energy potential to be used for self-sufficiency neighboring farms.

Table 3. Exploitable potential of Albian borehole in different cases

Settings	Low potential borehole	Average potential borehole	High potential borehole
Flow ($m^3.s^{-1}$)	0,05	0,1	0,3
Pressure (Pa)	10.10^5	16.10^5	28.10^5
Exploitable potential (kW)	50	160	840

Source: Authors.

Energy transforming and device integration

Inverted pump (PATs)

The excess head can be exploited for hydropower generation by using Pumps As Turbines (PATs) (Giugni *et al.,* 2014). PATs are pumps running in reverse mode, by inverting flow direction and using the electric motor as a generator (Chapallaz *et al.,* 1992; Tamm *et al.,* 2000). Only in recent years, the benefit of the use of PATs in water distribution networks was pointed out (De Marchis *et al.,* 2014), and so recovering energy using micro hydropower turbines on the flow of wastewater by the use of multiple pump-as-turbines in parallel is studied by (Power *et al.,* 2017). Jain and Patel (Jain & Patel 2014) provided a comprehensive review of the state-of-the-art of PATs, summarizing the main researches carried out (Pugliese *et al.,* 2016).

The energy diagram shown by (Chapallaz *et al.,* 1992) details the distribution of energy before and after the turbine. There is a good part of the total hydraulic energy that was absorbed by the turbine and which had to be transformed into electrical energy through the generator coupled directly to the shaft of the turbine.

The information necessary to calculate the power of the turbine inlet are obtained on the nameplate of motor–pump device. Hydraulic power is measured.

The generator output voltage is dependent on the number of rotations made by the turbine. The water gushes out of the turbine with an unused kinetic energy and discharged into the pool. The efficiency of the turbine is represented by the power supplied by the turbine divided by the power.

The PATs is subject to practically no effort since the latter is fed on water supplied by the tank, which pours it in the same tank. We obtained turbine efficiency of 22 %.

The groundwater level of the water tower is substantially fixed (level regulator); the electrical parameters of the PATs are invariable for a fixed output load. These require a constant hydraulic power at the input of the device.

Experimental turbine

The turbine dimensions are essentially derived from experimentation (Figure 4). After establishing some hypotheses (on the diameters to be chosen from the standard diameters), we obtained different dimensions.

Figure 4. Experimental turbine after machining and cleaning. In the left: Shell of the turbine, in the right: the wheel of the turbine.
Source: Authors

For each pair of data (DC [diameter of the pipe]; DT [Diameter of the impeller]), we have established the number of rotation N for various existing rates which are presented in Table 4. The number of rotations according to the flow moves in a linear regression with a slope of 3,83.

Table 4. Number of rotation for the different flow

Flow ($l.s^{-1}$)	Diameters 1 (m) DC = 0,10 DT = 0,20	Diameters 4 (m) DC = 0,125 DT = 0,25	Diameters of designed turbine (m) DC = 0,10 DT = 0,28
50	267,76	137,09	191,26
100	535,52	274,19	382,51
150	803,28	411,28	573,77
200	1071,04	548,37	765,03
250	1338,80	685,46	956,28
300	1606,56	822,56	1147,54
350	1874,32	959,65	1338,80
400	2142,07	1096,74	1530,05

Source : Authors

The dimensions selected for the diameter of the turbine wheel as well as for the pipe are respectively 0,28 m and 0,10 m, allowing an important coupling. The energy line is used to determine the distribution of energy (potential and kinetic), pressures and losses, and energy gains along a hydraulic circuit (Figure 5).

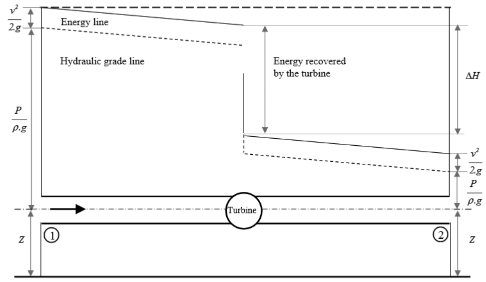

Figure 5. Energy diagram of a turbine in an installation, with "Z" reference height, "P" pressure "g" acceleration of gravity "r" the density and "v" the flow velocity.
Source: Authors

Figure 6, shows a longitudinal section of the modelled turbine. This cut allows distinguishing the internal components.

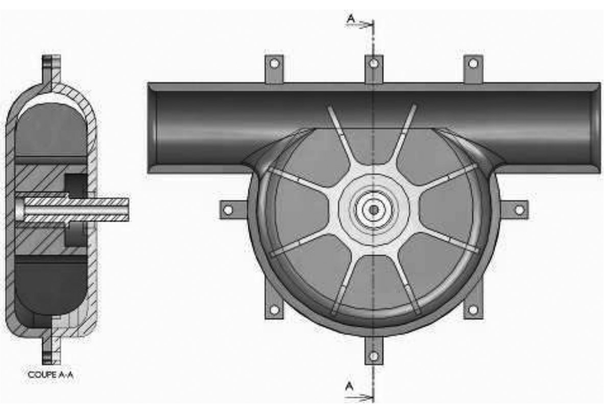

Figure 6. Cross section of the experimental turbine.
Source: Authors

Synthesis of the situation

The hydraulic power currently available within the borehole in exploitation is considerable; 250 kW and 150 kW at M'ghaier and Djama'a in Oued Souf (Table 3). Such hydraulic power can be usefully exploited for its transformation into electrical energy through turbine generators or inverted pumps (Ferreira, Camacho, Malagoli, & Júnior, 2016; Giugni, Fontana, & Ranucci, 2014).

Several type of turbine are used in micro hydropower (Branlard & Gaunaa, 2014; Kline, 1985; Simão & Ramos, 2010). It is difficult to settle for a turbine type, due to the nature of water energy. To simplify the matter, a trial with an experimental turbine to bring out this energy potential is to be undertaken. The integration of a turbo generator group is essential. An expert system named Small Hydropower Advisor (SHA), which was developed to make both the technical and legal issues behind a hydropower development accessible and understandable to everyone (Mohammadabad & Riordan, 2000) might be used in the future.

Small hydropower is one of the most attractive and probably the Oldest environmental friendly energy technology (Ferreira *et al.*, 2016). Small hydro potential is available on small rivers, canal heads, canal drops and Continental Intercalary borehole but only in the Northern Sahara.

However, we must consider that available hydraulic power gradually decrease over time due to aging borehole (CDARS, 1999a), as well as construction of other producing borehole and the growing interference of the fields of neighboring boreholes (M'ghaier, Djamaa and Touggourt) and therefore, the size of these groups must take account of these factors.

The micro hydropower in farms

Water cooling : The water arrives in the drill head at a pressure of 10.10^5 to 30.10^5 Pa and at a temperature of 40 to 80 °C (Hellal & Ourihane, 2004; S. Ouali *et al.*, 2006). This water, although abundant, is inadequate for direct use in agriculture including irrigation because its temperature is very high and can create in the plant certain reticence (Seasholes & DeVoil, 1998).

The water seeps through holes inside the cooler. It is set at the temperature of 30 °C on the cooling tower by forced ventilation through the transfer of heat by evaporation (Declaye, Gendebien, & Lemort, 2016).

Cooling the water is achieved through the water burst into fine droplets on metal plates (Declaye *et al.*, 2016; Oussedik, 2001). Atmospheric air, in contact with the water is heated and passes from the ambient humidity to a dampness close to saturation by evaporating a portion of the chilling water (Oussedik, 2001). The heat balance is shown in the Table 5.

Table 5. Heat balance of the cooling tower

Parameters	Value
Inlet water flow rate ($m^3.h^{-1}$)	468
Inlet water pressure (Pa)	105
Inlet water temperature (°C)	60
Air inlet flow rate ($m^3.h^{-1}$)	114 940
Inlet air temperature (°C)	30
Inlet air pressure (Pa)	105
Evaporated water outlet flow rate ($m^3.h^{-1}$)	22
Evaporated water outlet temperature (°C)	45
Outlet air flow rate ($m^3.h^{-1}$)	114 940
Wet air outlet temperature (°C)	45
Output flow water to be treated ($m^3.h^{-1}$)	446
Outlet temperature water to be treated (°C)	30

Source: Oussedik (2001)

The water-cooling tower is at a forced ventilation. The extraction of the hot and humid air is performed through an extractor of 5 m diameter, thus requiring a motor of 30 kW power. All this power is supplied from the national power grid. However, the existence of the Continental Intercalary hydropower, avoid to bring the external energy and waste that which is already available. The available energy from a single borehole may be more than enough for the extractor (Table 3). The rest of this energy can be used for other purposes in the neighboring farms.

Irrigation : Farms in the regions where the groundwater of Continental Intercalary is located, depends on Albian borehole. The location of the boreholes is very important to minimize the energy and financial expenses (Okot, 2013).

Farm's irrigation takes an important place in the invoice of expenses (Benmihoub & Bedrani, 2012). To make water reaches the last ramp of the pivot, a submersible pump of about 25 kW is recommended (Bruno Molle, Cyril Dejean, Daniel Colin, Jean-Marc Deumier, & Marsac, 2014) working for 18 hours non-stop. Peak hours cannot be avoided.

The fit out of a number of borehole with turbo-generator would supply the energy needs of the exploitation as well as surrounding ones. Indeed, it depends on the available water energy, the installed turbine and the irrigation system. At the end of the line, the integration of suitable turbine is possible, like the Schneider turbine that can generate power from relatively low-head hydroenergy sources such as rivers and irrigation canals (Morcos & Mikhail, 1986).

Amenities of neighboring farms : Farmers still need energy to develop cultivation, irrigation, farming, and personal comforts of their farms (Sourisseau, 2014; Weiland, 2013). The need for light, ventilation, cooling water, packaging of milk and other products requires energy (Zahm *et al.*, 2015).

The energy provided by borehole water can be enough to make up for a large part of these needs. Energy provided under thermal form may also be necessary during coldest times for heating greenhouses and surrounding installations (Dehina & Mokhtari, 2012).

Environment's turbine integration impact

Any hydroelectric development project has an impact on the environment and regional planning (Mottet & Lasserre, 2014; Perrin, 2015). They should always be within the sustainable development. But today, in most cases, technical solutions aid to limit the impact of these facilities on the local environment at quite acceptable level (Perrin, 2015).

The electrical set up includes the installation of electric poles, and the installation of voltage transformers. The integration of hydropower plants removes the previous installation and avoids hidden problems. Moreover, above all, because of its advantages and benefits, with low environmental impact, the small hydropower plants can be located closer to consumer centers. It is characterized by a small-occupied area and buildings with low environmental impact (Capik, Osman Yılmaz, & Cavusoglu, 2012; Nautiyal, Singal, Varun, & Sharma, 2011; Okot, 2013).

Conclusion

The quality of life and safeness of the present and future generations are strongly intertwined with the availability of energy sources and the sustainability of the energy infrastructure (Stambouli, Khiat, Flazi, & Kitamura, 2012).

Water's resources in Algeria are estimated at 18 billion m^3, of which 10 billion m^3 of surface resources, 2,5 billion m^3 of groundwater resources in the North and 5,5 billion m^3 mainly underground in the South (MRE, 2014). Therefore, one of the fundamental priorities for a country such as Algeria is to use several renewable energies (RE) sources and environmentally friendly energy conversion technologies (Stambouli *et al.*, 2012).

Undoubtedly, the Continental Intercalary is an asset for the economic development of the Algerian Sahara especially in areas where this source is shallow and gushing.

The Albian groundwater is a huge reservoir providing power without restraint. The lifetime of this energy is limited to maximum 40 years according to the simulations already made (OSS, 2003); subject to significant climate change.

The energy generated by a commonly used borehole is about a hundred kilowatts. The minimum estimate is 35 kilowatts in most artesian borehole.

The level of production of small hydroelectric power plants is insufficient, contributing very little to Algeria's energy balance. Production of hydraulic sector represents only 389,4 GWh of 28 950 GWh generated by the SPE power generation subsidiary company of Sonelgaz, while the bulk of electricity production (18 723 GWh), is provided by gas (Hamiche, Stambouli, & Flazi, 2015; MEM, 2014; Stambouli *et al.*, 2012).

It seems crucial to make attention to these energies, not to develop mass production, but to save, control and orient the distribution of conventional energy; assuring that a sustainable development is respected.

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