Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.928236

55 (2015) 1725–1734
August

Taylor & Francis
Taylor & Francis Group

Diagnostic of electricity consumption, its cost and greenhouse gas emission in the wastewater treatment sector of Algeria

S. Igoud[a,b,*], F. Souahi[a], C.E. Chitour[a], A. Adjrad[a], M. Habchi[a], A. Chouikh[c]

[a]*Department of Chemical Engineering, University of Polytechnic, Hacène Badi, El Harrach, Algiers 16200, Algeria, Tel. +213 24 41 01 33; emails: igoud.sadek@udes.dz, igoud_sadek@yahoo.fr (S. Igoud), Tel. +213 21 52 01 27; email: fsouahi@yahoo.fr (F. Souahi)*
[b]*Development Unit of Solar Equipments, EPST/CDER, National road No. 11, P.O. Box 386, Bou-Ismail, Tipasa 42135, Algeria*
[c]*National Sanitation Office (ONA), Crossroads of Sidi Arcine, Road of Baraki, Algiers, Algeria, Tel. +213 21 76 20 34; email: amarchouikh@yahoo.fr*

Received 4 December 2013; Accepted 21 May 2014

ABSTRACT

Wastewater treatment sector, in Algeria, uses exclusively two processes: the activated sludge applied in the north and the lagooning in the highlands and the south. In the operating balance of the National Sanitation Office (ONA), the activated sludge wastewater treatment plants are characterized by a high electricity consumption which induced high cost and greenhouse gas (GHG) emission. In 2010, about 104.32 million m^3 of wastewater was treated. This operation consumed 30,900 MWh of electricity which cost 1.04 million Euros (€) and emitted 18,761 tons of CO_2-equivalent. In 2013, the treated wastewater increased by 35.2% and the electricity consumption by 45.8%. To establish an exhaustive diagnostic, this study evaluated the electricity consumed during 2009/2010 in an activated sludge wastewater treatment plant of 70,000 population equivalents (PE) (i.e. Unit of a pollution load produced daily per person, fixed at 60 grams of DBO_5, which is used for the sizing of the wastewater treatment plants). Three areas were investigated: (1) the treatment process which consumed 89.63% of electricity; (2) the management department and the laboratory with 4.60%; and (3) the outdoor lighting with 5.77%. The biological treatment was the intensive-energy part of the treatment which consumed 70.05% of electricity. The aim of this diagnostic was to evaluate the performance level of the activated sludge wastewater treatment process relatively to the energy, financial and environmental factors in order to optimize the process and, then, to evaluate the benefit that could be provided by the integration of renewable energy in a sustainable wastewater treatment context.

Keywords: Algerian wastewater treatment sector; Activated sludge process; Electricity consumption; Electricity cost; Greenhouse gas emission

1. Introduction

Water and energy resources availability, as well as environmentally sustainable development, represents the major challenge faced by nations with growing economies and populations [1–3]. Furthermore, unrestrained exploitation of the earth's natural resources has already resulted in major environmental problems such as air, water and soil pollution [4–7].

*Corresponding author.

Water pollution and scarcity will affect, in particular, poor countries located in arid areas of the world where it is already estimated that 1.2 billion people have got drinkable water [8]. In arid areas like North Africa, Middle East, Central and west Asia, water scarcity and its poor quality constitute a growing concern not only for freshwater supplies but also for agricultural and industrial activities [8,9].

Furthermore, all over the world, people become aware of the environmental and economic consequences induced by the lack of potable water [10–13]. To counter these threats, significant investments have been made in municipal and rural areas to satisfy the domestic, industrial and agricultural water demands of society.

In the field of clean water supply, Algeria is vulnerable inherently because of its geo-climatic location in the north of Africa. The region along the southern Mediterranean coast is sub-humid. However, the majority of the countries in the south are semi-arid and arid regions characterized by low rainfall and high temperature. An ambitious programme [14] was established to increase water resources in these regions through the rational exploitation of surface water and dams, the exploration of new groundwater, the use of desalinated seawater and the reuse of treated wastewater. Effectively, the total volume of treated wastewater was discarded without reuse despite the fact that it constitutes an important water resource estimated at 1.2 billion m^3 yearly [15]. Now, the Algerian government plans the wastewater reuse and the increase in its collect and treatment [14]. In the Five-Year Plan 2010/2014, funds are provided for the building of 40 new wastewater treatment plants (WWTP). They will be added to the 123 existing ones to treat the totality of rejected wastewater [14]. The new plants will be located in cities and coastal towns that have a population of more than 1000,00 people.

Although this strategic policy is imperative to secure water resources, the plan will significantly increase electricity consumption and management costs in the wastewater treatment sector. Moreover, this will induce important environmental damages, especially concerning the greenhouse gas (GHG) emission because of the significant electricity consumption generated by fossil energy. The same consequences will affect all countries that suffer from water shortages and where an increase in water supplies will be sought using energy generation through unsustainable fossil fuel consumption. In Saudi Arabia, for example, water pumping and desalination consume over 9% of the total annually generated electricity. The same trend is observed in other Arabian Gulf countries where 5–12% of the total electricity generated is consumed by the desalination system [9].

The situation becomes more complex if the water–energy nexus is considered, because the increase in water demand is positively correlated with the energy consumption. Water pumping and wastewater treatment consume 7–8% of the global energy production [9,16–18]. Between 2006 and 2030, the International Energy Agency expects that the energy needs of wastewater treatment will increase by 44% [19]. Now, if the water–energy–food interaction is considered, it can be seen that food security requires both water and electricity. In 2050, a food increase of 70% will induce an increase of 20% of agricultural water consumption [18,20].

2. The Algerian wastewater treatment sector

The total volume of wastewater has increased continuously over the last decade. In 1999, it was estimated at 600 million m^3; it represents a ratio of 19.88 m^3/inhabitant. In 2010, this volume had increased by 100% to reach 1.2 billion m^3; this corresponded to a ratio of 32.34 m^3/inhabitant for a collecting rate estimated at 86% [15]. This percentage is higher than the three-fifths of the Europe Member States, fixed at 70% [21]. It is also comparatively superior to the Arab Countries fixed at 60% in 2010 [22]. Several factors have resulted in the increase in the wastewater volume, especially the upsurge in urban populations with the corresponding rises in potable water consumption. Indeed, drinking water volume, which was estimated at 1.4 billion m^3 in 1999, representing 40.46 m^3/inhabitant, has increased by 100% in 2009. The increase was also due to the rejection of both rainwater and industrial wastewater in the single combined sewerage network [15].

Over the last decade, significant investments were injected in this sector for the increase in the sewerage network length. In 1995, the sewage network collected about 79% of discarded wastewater; the rest was rejected in natural areas (i.e. Mediterranean Sea, rivers, etc.). This percentage increased to 86% in 2010 and represents about 41,000 km of sewage network. It is planned that, by 2020, the network should reach 54,000 km [15,23].

In the same manner, the number of WWTPs evolved despite the fact that treated wastewater was not reused until 2012 when legal provisions were taken [24]. The number of plants was 18 in 2000 and increased, in 2011, to 123 that were managed mainly by ONA and the local authorities, building operators and stock companies in major cities [15]. Since 2006, new stock companies were also formed, namely SEAAL (www.seaal.dz), SEOR (www.seor.dz), SEACO (www.seaco.dz) and SEATA (www.seata.dz), which group with ONA (www.ona.dz), the Algerian water company (ADE www.ade.dz) and SUEZ environment (www.suez-environnement.fr).

3. Tipasa wastewater treatment location and process

In 2010, Tipasa WWTP, was one of the 68 WWTPs managed by ONA. It is located in Chenoua area, which is 70 km west of Algiers.

The plant is conceived to treat urban wastewater of 70,000 PE. It processed daily 5,714.77 m^3 of raw wastewater at 35% of its capacity. The treatment is based on the activated sludge process at low load with extended aeration, which allowed an optimized treatment in a small area. In 2010, the remediation efficiency reached 98% in BOD and 86% in COD [25].

As shown in Fig. 1, the process begins from the sewage lift (stage A), where raw wastewater is rejected by the sewage network into a collector (i.e. the collector regulates a constant wastewater flow designed for an optimum treatment). At this stage, raw wastewater passes through a first screening system from which it is relieved by pumping and transferred to the stage B. The last stage is a pre-treatment operation where a second screening system and a grit-oil separator are used to eliminate huge waste, sand and oil. After this stage, pre-treated wastewater is conveyed towards the aeration tank where it is continuously aerated by six 75-kW propeller aeration machines. This biological treatment (stage C) is based on the activation of the aerobic micro-organisms, naturally found in the wastewater. Their development induced the organic matter reduction (i.e. the organic matter is transformed into carbon dioxide, water and other inorganic compounds) to achieve an activated sludge concentration of 30 mg/l. The last operation is the clarification (stage D) where two conical tanks recover the sludge from the bottom of the tanks and the clarified water from their summit. A part of the recovered sludge is returned to the aeration tank. The sludge excess, estimated daily at 130 m^3, is evacuated towards the conditioning operation (stage E). At this level, another settling tank is used for sludge decantation. Then, the thickened sludge is pressed by a belt press to reduce dryness from 3.5 to 20%. At the end of the treatment process, treated wastewater is discharged into a stream, and the dehydrated sewage sludge, estimated yearly at 3,040 tons, is released into a landfill site.

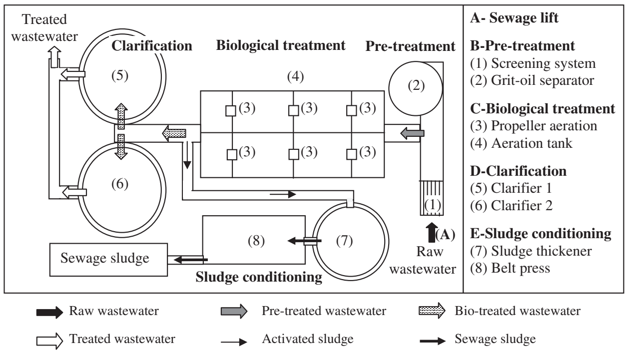

Fig. 1. Tipasa wastewater treatment plant flow diagram.

4. Methodology

4.1. Evaluation of the conventional electricity consumption and its cost

In the first step, all electrical equipment used in the WWTP process and their electrical power were identified. In the second step, for all equipment, the daily uptime and its hourly distribution were recorded from hourly counters of the dashboard plant. The last step permits the elaboration of a database where the daily and the monthly uptimes and their hourly distribution are saved. These two steps allowed the assessment of the daily, monthly and yearly electricity consumption of the electrical equipment. Moreover, the calculation of their electricity consumption and their cost was carried out using the hourly distribution of the electricity consumed according to the hourly electricity price plan used in Algeria [26].

For the office building, including the management department and the laboratory, electricity consumption and its cost were estimated taking into account the electrical power of the offices and laboratory equipment used during the Algerian administrative work hours. For the outdoor lighting, the electricity consumption and its cost were evaluated considering the bulbs' electrical power and their daily uptime during the darkness periods.

In Algeria, the plan of the hourly electricity prices fixes the rates at 6.92 centime Euros per kWh (c€/kWh) during the peak load period, at 1.53 c€/kWh during the base load period and at 0.81 c€/kWh during the off-peak load period.

The peak period is fixed from 5 pm to 9 pm, the base period from 9 pm to 10.30 pm, equally from 6 am to 5 pm and the off-peak hours from 10.30 pm to 6 am [27].

4.2. Evaluation of the GHG emission

During the WWTP operation, the electricity consumed was generated at a national level and delivered by the interconnected national distribution network. The assessment of GHG emission, induced by the WWTP electricity consumption, required the determination of the primary fuel burned during its generation. During the study period, electricity was generated from 96% of natural gas characterized by a net calorific value of 42.3 MJ/m^3 [26]. Three types of technologies were used, namely gas turbines, steam turbines and combined cycle, which contributed 56, 22 and 18%, respectively, to produce electricity. Each technology has, respectively, a conversion efficiency rate of 35, 40 and 55% [28].

During the electricity generation, the total volume of natural gas consumed by the three used technologies was calculated as follows (Eq. (1)):

The calculation of the volume of natural gas fuel, characterized by a PCS 42.3 MJ/m^3 [15], was determined from the equation yields:

$$NGC = \sum_{i=30\%}^{55\%} EC \cdot PR/NCV \cdot \eta i \quad (1)$$

where NGC is the Natural gas consumption (m^3), EC is the Electricity consumed (kWh), PR is the Participation rate (%), NCVis the Net calorific value (kWh/m^3) and η is the Conversion efficiency (%)

The rest of the electricity produced, about 2% [28], was generated by hydroelectric turbines with a GHG emission estimated at 9 g of CO_2-eq/kWh [29]. Electrical losses due to distribution via the interconnected national network were evaluated at 4.5% of the total production [28].

The 2% of the electricity generated from diesel generators is not taken into account. This electricity is not injected into the national distribution network but it is consumed in remote areas.

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions were calculated according to the Tier 1 approach of IPCC guidelines [30] as follows (Eq. (2)):

$$\text{Emissions GHG}_{\text{fuel}} = \text{Fuel Consumption}_{\text{fuel}} \cdot \text{Emission Factor GHG}_{\text{fuel}} \quad (2)$$

From Eq. (2), the GHG emissions are performed using Eq. (3):

$$GHG = \sum_{GHG}^{CO_2, CH_4, N_2O} NGC \cdot NCV \cdot DEF \cdot GWP \quad (3)$$

where GHG: Greenhouse gas emission (kg of CO_2-eq), NGC: Natural gas consumption (m^3), NCV: Net calorific value (Tj/m^3), DEF: Default emission factor (kg GHG/TJ), GWP: Global Warming Potentials (100-years time frame).

5. Results and discussion

5.1. Electricity consumption

In the WWTP, the yearly electricity consumption was estimated at 1,249.72 MWh; this represents a ratio of 0.6 kWh/m^3. About 90% of the electricity was consumed by the wastewater treatment process to treat a yearly wastewater volume estimated at 2.08 million m^3. The remaining was consumed by the management department and laboratory, estimated at 4.6% and the outdoor lighting, evaluated at 5.77% (Fig. 2).

The biological treatment consumed the highest part of electricity, estimated at 70.05%. This is due to the aeration of the biological tank where six 75-kW propeller aeration machines are continuously used (cf. Fig. 1). This stage of treatment induced the most important operating budget, evaluated at 15,468.35 €. However, this percentage is up to the limits as it consumes between 50 and 60% of the electricity as reported by the literature [31]. In other studies, the electricity consumption rate is extended until 80%, while the upper limits indicate the need for aeration optimization [32]. In Tipasa WWTP, which became operational in 2008, the high electricity consumption should be induced by the high BOD reduction, estimated at 98%, and its low treatment capacity. Often, in new WWTPs, the sizing is calculated for a lifetime of 25 years, which is not reached at the beginning of the operation.

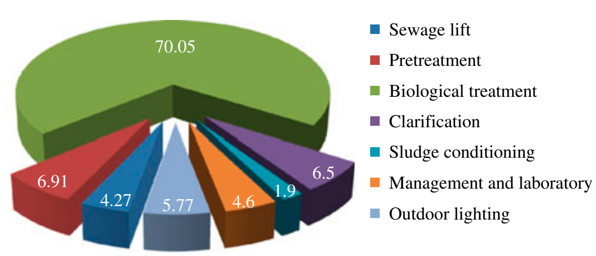

Fig. 2. Distribution of the yearly electricity consumption in Tipasa wastewater treatment plant (2009/2010).

Table 1
The yearly electricity cost of the wastewater treatment plant management

Investigated stages	Yearly cost (€)	Yearly cost (%)
A–Sewage lift	1,670.83	6.74
B–Pretreatment (1) + (2)	2,211.20	8.92
C–Biological treatment 6.(3)	15,468.35	62.45
D-Clarification 2.(5)	1,772.02	7.15
E–Sludge conditioning (7) + (8)	412.27	1.66
Wastewater treatment process	21,534.68	86.95
Management department and laboratory	1,763.38	7.12
Outdoor lighting	1,468.17	5.93
Wastewater treatment plant	24,766.23	100

Note: Letters A–E and number 1–8 refer to Fig. 1.

5.2. Electricity cost

The electricity consumed during the WWTP management costs 24,766.23 € (Table 1). The ratios of the electricity consumption and its cost are estimated at 0.6 kWh/m^3 and 1.18 c€/m^3. Comparatively to the Algiers area where the activated sludge process is exclusively applied in the 4 WWTPs, Tipasa's ratio is higher. It is estimated at 0.4 kWh/m^3 [25]. At the opposite, the electricity cost is lower compared with Algiers ratio which is estimated at 1.31 c€/m^3. This is explained by the interruption of the aeration machines operation during the peak hours for the reduction in the treatment cost.

The ratios of the plant are also higher compared with the wastewater treatment conducted in the 68 WWTPs managed by ONA. At this level, the electricity consumption ratio is fixed at 0.42 kWh/m^3 and the cost at 1 c€/m^3. This is due to the combination and use of the activated sludge and lagoon processes that reduce the electricity consumption and its cost.

5.3. GHG emission

The electricity consumed during the plant operation was generated by the national electricity grid.

Table 2 shows that more than half of the electricity consumed in the WWTP was generated by the gas turbine technology. Due to its low efficiency, this technology emitted the highest quantity of GHG intensity estimated at 160 g of CO_2-eq/kWh. Stream turbine and combined cycle technologies are characterized by higher efficiency rates evaluated, respectively, at 40 and 55%; this results in less GHG emission. The GHG emission was estimated at 140 g of CO_2-eq/kWh when the stream turbine is used and at 102 g of CO_2-eq/kWh when the combined cycle technology is used. Finally, the lowest amount of GHG emission, estimated at 9 g of CO_2-eq/kWh, was emitted by hydroelectric technology (diesel electricity generation was not taken into account, cf. 4.1).

These data permit to conclude that the yearly electricity consumption, evaluated at 1,249.72 MWh,

Table 2
GHG emission induced by the electricity consumption in Tipasa wastewater treatment plant

Technology used for electricity generation	Participation rate (%)	Tipasa wwtp electricity consumption (kWh)	Conversion rate (%)	Natural gas consumed (10^3 m^3)	GHG emission			GHG intensity (t CO_2-eq)
					CO_2 (kg)	CH_4 (kg)	N_2O (kg)	
Gas turbine	56	699,847.12	35	47.28	112,175.50	42.00	62.00	112.28
Stream turbine	22	274,939.94	40	16.25	38 .56	14.43	21.30	38.60
Combined cycle	18	224,950.86	55	9.67	22.94	8.58	12.68	22.96
Hydro-electricity	2	24,995	–	–	–	–	–	0.22
Diesel turbine	2	–	–	–	–	–	–	
Total	98	1,224,733		73.2	173.68	65.01	96.00	174.06
Total	104.5	1,305,965						185.61

Table 3
Evaluation of the GHG emitted during the wastewater treatment managed by ONA in 2010

Area location	Number of WWTPs	Wastewater treatment processes			Wastewater treated or pumped (10^6 m^3)	Remediation efficiency (%)		Electricity consumption (MWh)	Electricity consumption /total (%)	Ratio (kWh/m^3)	Cost (10^3 €)	GHG emission (t CO_2-eq)
		Lagooning	Aerated lagooning	Activated sludge		BOD	COD					
Algiers	4	–	–	4	8.29	96	88	3,331.42	10.78	0.40	104.14	473.48
Tizi-ouzou	13	–	–	13	15.82	95	90	5,089.27	16.7	0.70	163.67	723.32
Sétif	8	3	1	4	10.07	79	83	3,638.72	11.77	0.61	133.64	517.15
Constantine	3	–	–	3	5.23	95	91	2,099.34	6.80	0.76	84.31	298.37
Annaba	4	–	–	4	12.86	95	89	4,338.10	14.03	0.61	151.82	616.55
Batna	1	–	–	1	5.00	97	90	1,690.63	5.47	0.74	56.68	240.28
Chlef	3	–	1	2	6.03	98	92	2,565.52	8.30	0.80	80.11	364.62
Tiaret				1	0.69	35	62	0,300.98	1.00	–	7.79	42.77
Oran	22	15	3	4	21.13	88	87	4,622.22	14.96	0.30	16.380	656.93
Saida	6	2	2	2	3.70	93	89	1,795.49	5.81	0.77	71.48	255.18
Ouargla	3	1	1	1	13.62	84	86	1,209.94	3.91	0.20	29.05	171.96
El Oued	1	–	1	–	1.83	80	80	0,218.50	0.70	0.24	–	31.05
TOTAL treatment	68	21	9	38	104.32	92	88	30,900.18	100.00	0.29	1,046.52	4,391.72
TOTAL lifting	215				129.72			13,443.21		0.10	540.03	1,910.63
TOTAL								44,343.39		0.42	1,586.82	6,302.36

Table 4
Average ratio of energy consumed for wastewater treatment in 2010 [25,31]

Netherlands	Australia	Algeria (ONA)	USA	Switzerland	Spain	Singapore	United Kingdom	Germany
0.36	0.39	0.42	0.46	0.52	0.53	0.56	0.64	0.67

emitted 177.62 tons of CO_2-eq. The consideration of the electricity lost by the interconnected network (4.5% cf. 4.2) added 56,237.71 kWh to the balance. This induced a total GHG emission of 185.61 tons of CO_2-eq with a GHG intensity of 142.12 g of CO_2-eq/kWh.

The GHG intensity is significantly lower compared with the national average estimated, in 2009, at 574 g of CO_2-eq/kWh [33]. However, it is to note that the national average of GHG emissions was estimated according to electricity and heat generation using natural gas. Equally, in Algeria, natural gas is generally the unique fuel combusted for heat generation.

5.4. Electricity consumption, cost and GHG emission of the WWTPs managed by ONA

The activated sewage sludge process was applied in 38 WWTPs for a total of 68 (Table 3). Moreover, the aerated lagoon process, applied in nine WWTPs, increases the electricity consumption. Effectively, as shown in Tipasa WWTP (cf. Fig. 2), the engines used for the extended aeration consumed 70.05% of the plant's electricity. The lower electricity rate is consumed by the lagoon process which is applied only by 30% in the WWTPs.

During 2010, the treatment of the total volume of 104.32 million m^3 wastewater consumed 30,900 MWh of electricity in addition to the 13,443 MWh consumed by the sewage lift. (i.e. sewage lift is used to pump wastewater from the underground sewage network to the WWTPs level) [19]. Table 3 shows that the total amount of the electricity consumed for the wastewater treatment and sewage lift cost 1.58 million € and induced the emission of 6,302 tons of CO_2-equivalent.

The ratio of the energy consumption per m^3 of treated wastewater does not differ considerably between the different Algerian WWTPs. It ranges from 0.20 kWh/m^3, in Ouargla, to 0.4 kWh/m^3, in Algiers.

In comparison with other countries (Table 4), the average energy consumed in the Algerian wastewater treatment sector, estimated at 0.42 kWh/m^3, is relatively low. It ranges between the Australian ratio, estimated at 0.42 kWh/m^3, and the USA ratio, fixed at 0.46 kWh/m^3.

During 2013, the building of 28 new WWTPs has increased ONA's wastewater treatment capacity. However, the only two wastewater treatment processes, namely the activated sewage sludge and the lagooning, still apply in 77% of the plants.

The total volume of treated wastewater was estimated at 161 million m^3. Compared to 2010, this represents an increase of 35.2%. The yearly energy balance estimated the electricity consumption at 60,283.3 MWh, in the wastewater treatment, with an increase of 48.74% relatively to 2010. In the sewage lift, the electricity consumed was evaluated at 21,675.65 MWh, representing an increase of 38% compared to 2010 [34]. Regarding the total amount of the consumed electricity, evaluated at about 82 MWh, an increase of 45.8% was recorded in comparison with 2010. This has cost 1.58 million € and induced an emission of 6,302 tons of CO_2-equivalent (Table 5).

6. Conclusion

The investigation on the activated sludge process, during 2009–2010, applied for the wastewater treatment in Tipasa plant, estimated the yearly electricity consumption at 1,249 MWh. This represents 4% of electricity consumed in the Algerian wastewater treatment sector which induced a cost of 24,766.23 € and an emission of 185.61 tons of CO_2-eq.

89.63% of the electricity was consumed by the treatment process, 4.60% by the management department and laboratory and 5.77% in the outdoor lighting. The share of the electricity consumption showed that the biological treatment consumed the largest quantity of electricity, estimated at 70.05% and the most important operating budget, evaluated at 62.45%. The consumed electricity rate exceeds the international limit which is between 50 and 60%; it increases the consumed electricity ratio by m^3 of treated wastewater until 0.6. The rest of the electricity was consumed at 6.91% in the pre-treatment, 6.5% in the clarification, 4.27% for the sewage lift and 1.9% for the sludge conditioning.

At the national level, the intensive-energy aeration was used in 70% of the wastewater treatment plants managed by ONA. In 2010, the treatment of 104 million m^3 of wastewater consumed 44,343 MWh which cost 1.58 million € and induced an emission of 6.32 10^3 tons of CO2-equivalent. In 2013, the use of the

Table 5
Evaluation of the GHG emitted during the wastewater treatment managed by ONA in 2013

Area location	Number of WWTPs	Wastewater treatment processes			Wastewater treated or pumped (10^6 m^3)	Remediation efficiency (%)		Electricity consumption (MWh)	Electricity consumption/total (%)	Ratio (kWh/m^3)	GHG emission (t CO_2-eq)
		Lagooning	Aerated lagooning	Activated sludge		BOD	COD				
Algiers	5	–	1	4	9.65	95	88	4,258.25	7.06	0.44	605.21
Tizi-ouzou	12	–	–	12	11.46	93	91	5,555.00	9.21	0.48	789.50
Sétif	9	3	1	4	11.90	79	83	8,087.52	13.41	0.68	1,149.45
Constantine	3	–	–	3	8.24	96	93	3,049.60	5.05	0.37	433.43
Annaba	5	–	–	5	22.13	82	92	6,693.34	11.10	0.30	951.30
Batna	7	4	–	3	12.41	73	86	3,017.86	5.00	0.24	430.00
Chlef	3	–	1	2	4.77	86	88	2,857.82	4.74	0.60	406.17
Tiaret	8	2	2	4	16.08	88	87	10,115.20	16.78	0.63	1,437.63
Oued Righ	2	1	–	1	1.14	92	89	–			
Oran	30	18	8	4	31.40	75	80	5,941.48	9.85	0.20	844.44
Béchar	2	1	–	1	1.88	82	84	78,109.00	0.01	0.04	11.10
Laghouat		1	2	1	7.90	–	95	2,783.128	4.61	0.35	395.55
El Oued	4	–	4	–	8.05	73	78	3,944.03	6.54	0.9	560.55
Ouargla	3	1	2	–	14.00	75	68	3,902.02	6.47	0.28	554.58
TOTAL treatment	96	21	9	38	161.01	92	88	60,283.30	100.00	0.37	8,567.84
TOTAL lifting	337				201.73			21,675. 65		0.10	3,080.68
TOTAL								81, 958.96		0.50	11,648.52

intensive-energy aeration evolved to 77%. The volume of treated wastewater has increased by 35.2%, inducing an increase in the electricity consumption and GHG emission by 45.8%. Regarding the ratio of the electricity consumption per m^3 of treated wastewater, it has evolved from 0.42 to 0.5.

In perspective, ONA investigates the optimization of the electricity consumption, first, by the reduction in the operation duration of the aeration engines. Then, it plans the local electricity generation in each wastewater treatment plant using the biogas cogeneration and the solar photovoltaic electricity generation in a sustainable context.

Acknowledgements

The authors thank all those who have contributed to the writing of this article, especially Mr Ahmed and Toufik Medjiah from Tipasa's wastewater treatment plant, Miss A. Chalal from the Development Unit of Solar Equipment at Bou-Ismaïl and Mr Khaled Ameur from CanmetÉNERGIE, Varennes, Ressources naturelles at Canada.

References

[1] C. Karakosta, D. Askounis, Developing countries' energy needs and priorities under a sustainable development perspective: A linguistic decision support approach, Eng. Sustainable Dev. 14 (2010) 330–338.
[2] Y. Jiang, China's water scarcity, J. Environ. Manage. 90 (2009) 3185–3196.
[3] M. Qadir, B.R. Sharma, A. Bruggeman, R. Choukr-Allah, F. Karajeh, Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries, Agric. Water Manage. 87 (2007) 2–22.
[4] K.-E. Percy, M. Ferretti, Air pollution and forest health: Toward new monitoring concepts, Environ. Pollut. 130 (2004) 113–126.
[5] E.-A. Gilla, C.-L. Curl, S.-D. Adar, R.-W. Allen, N. Auchincloss, M.-S. O'Neill, S.-K. Park, V.-C. Van Hee, A.-V. Diez Roux, J.-D. Kaufman, Air pollution and cardiovascular disease in the multi-ethnic study of atherosclerosis, Prog. Cardiovasc. Dis. 53 (2011) 353–360.
[6] L.-J. Bao, K.-A. Maruya, S.-A. Snyder, E.-Y. Zeng, China's water pollution by persistent organic pollutants, Environ. Pollut. 163 (2012) 100–108.
[7] J. Nahmani, P. Lavelle, Effects of heavy metal pollution on soil macrofauna in a grassland of Northern France, Eur. J. Soil Biol. 38 (2002) 297–300.
[8] Human Development Report, Beyond Scarcity: Power, Poverty and the Global Water Crisis, UNDP, United Nations Development Programme, UNDP, New York, NY, 2006.
[9] A. Siddiqi, L.D. Anadon, The water–energy nexus in Middle East and North Africa, Energy Policy 39 (2011) 4529–4540.
[10] R. Al-Weshah, The role of UNESCO in sustainable water resources management in the Arab World, Desalination 152 (2002) 1–13.
[11] R.M. Kirby, J. Bartram, R. Carr, Water in food production and processing: Quantity and quality concerns, Food Control 14 (2003) 283–299.
[12] J. Ibáñez, J. Valderrama, J. Puigdefábregas, Assessing overexploitation in Mediterranean aquifers using system stability condition analysis, Ecol. Modell. 218 (2008) 260–266.
[13] S. Bouri, B.H.A. Dhia, A thirty-year artificial recharge experiment in a coastal aquifer in an arid zone: The Teboulba aquifer system (Tunisian Sahel), C.R. Geosci. 342 (2010) 60–74.
[14] Five-year development program 2010/2014. Available from: http://www.mae.dz/photos/gov/programme.htm.
[15] H. Hammouche, Algeria Report Country, Experts Consultation on Wastewater Management in the Arab World, The Arab Water Council, Dubai, May 2011.
[16] P. Praveena Sri, The Electric Energy–Water Nexus: Managing the Seasonal Linkages of Fresh Water Use in Energy Sector for Sustainable Future, Indira Gandhi Institute of Development Research, Mumbai, 2010.
[17] J. Blanco, S. Malato, P. Fernández-Ibañez, D. Alarcón, W. Gernjak, M.I. Maldonado, Review of feasible solar energy applications to water processes, Renewable Sustainable Energy Rev. 13 (2009) 1437–1445.
[18] Managing water under uncertainty and risk. Facts and figures from the United Nations world water development report 4 (WWDR4), United Nations World Water Assessment Programme, UNESCO-WWAP, 2012.
[19] International Energy Agency, World Energy Outlook 2009, IEA, Paris, 2006.
[20] M. Bazilian, H. Rogner, M. Howells, S. Hermann, D. Arent, D. Gielen, P. Steduto, A. Mueller, P. Komor, R.S.J. Kandeh, K. Yumkella, Considering the energy, water and food nexus: Towards an integrated modeling approach, Energy Policy 6 (2012) 342–349.
[21] Water statistics, Wastewater treatment, Eurostat, European Commission. Available from: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Water_statistics.
[22] Wastewater Reuse in Arab Countries, Comparative Compilation of Information and Reference List, ACWUA Report. Available from: http://www.ais.unwater.org/ais/pluginfile.php/356/mod_page/content/119/Jordan_Summary-Report-CountryCasestudies_final.pdf.
[23] National office of statistics. Available from: www.ons.dz.
[24] Inter ministerial decrees corresponding to 2 January 2012 laying down the specifications of treated wastewater used for irrigation and the list of crops that can be irrigated with treated wastewater, Official Journal of Algerian Republic No. 41.
[25] Bilan annuel d'exploitation, exercice 2010, document interne (Internal document), Office National de l'Assainissement, Ministère des Ressources en Eaux, Algérie, 2010.
[26] Décision D/06-05/CD du 30, Mai 2005 portant fixation des tarifs de l'électricité et du gaz, Commission de Régulation de l'Electricité et du Gaz GREG

[Decision D/06-05/CD of 30th May 2005 relating to the fixing prices of electricity and gas. Commission of the regulation of electricity and gas CREG]. Available from: http://www.mem-algeria.org/actu/comn/creg_decision-tarifs.pdf.
[27] Loi No 02-01 du 22, Dhou El Kaada 1422 correspondant au 5 février 2002 relative à l'électricité et à la distribution du gaz par canalisations (Dhou El Kaada 1422 corresponding to 5 February 2002 relative to the electricity and gas distribution).
[28] Rapport d'activité, document interne, Commission de Régulation de l'Electricité et du Gaz (Regulatory Commission of Electricity and Gas), CREG 009, Algérie, 2010.
[29] A. Kumar, T. Schei, A. Ahenkorah, R. Caceres, J.-M. Devernay, M. Freitas, D. Hall, Å. Killingtveit, Z. Liu, Chapter 5, Hydropower, in: O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (Eds.), IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, Cambridge, pp. 437–496.
[30] The National Greenhouse Gas Inventories Programme, Chapter 2, Stationary combustion, in: H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, K. Tanabe (Eds.), Guidelines for National Greenhouse Gas Inventories, Volume 2, Energy, IGES, Japan, 2006, pp. 2.1–2.47. Available from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf.
[31] F. Hernández-Sancho, M. Molinos-Senante, R. Sala-Garrido, Energy efficiency in Spanish wastewater treatment plants: A non-radial DEA approach, Sci. Total Environ. 409 (2011) 2693–2699.
[32] Suivi des systèmes d'assainissement collectifs en Seine-et-Marne, Observatoire de l'eau, Conseil général de Seine-et-Marne, Direction de l'eau et de l'environnement, 2011, 96 (in French).
[33] CO_2 emission from fuel combustion highlights, IEA statistics, 2011. Available from www.iea.org/media/statistics/CO2highlights.pdf.
[34] Bilan annuel d'exploitation, exercice 2013, document interne (Internal document). Office National de l'Assainissement, Ministère des Ressources en Eaux, Algérie, 2013.