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Renewable energies: an alternative for production and saving electricity in the field of water and sanitation

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This synthesis « **Renewable energies: an alternative for production and saving electricity in the field of water and sanitation** » was performed by **Juline Lange,** student in the AgroParisTech-ENGREF specialized master "Water Management" (post-master degree) in Montpellier.

TECHNICAL SYNTHESIS

Renewable energies: an alternative for production and saving electricity in the field of water and sanitation.

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ABSTRACT

In response to the need for high quality drinking water and wastewater treatment, new production and treatment systems have been developed. Therefore, drinking water plants and wastewater treatment plants need more and more energy to operate. Moreover, following the *Grenelle Environment (Forum)*, a French bill on energy transition have been established and requires the share of renewable energy to reach 32% by 2030. This raises questions about renewable energies as an efficient solution to save costs and energy.

Firstly, this synthesis focuses on the most significant costs in terms of energy consumption in drinking water production and wastewater treatment processes, and on the areas in which it is possible to implement renewable energy systems. Following on from this, three different kinds of renewable energies (solar energy, wind energy, biogas) are presented and illustrated through examples. Then, we shall conclude this work with an analysis of the technical, economical, and regulation limitations and constraints relating to the use of renewable energy.

This synthesis demonstrates that there are many methods to control energy consumption. Renewable energies alone cannot significantly reduce the consumption of energy and ensure electricity supply for drinking water and wastewater treatment plants. The solution seems to be an energy mix that would optimize the needs for electricity in order to reduce them, while consuming another kind of energy, like renewable energies.

Key-words: Renewable energies, water production, sewage treatment plant, drinking water, wastewater, sludge, solar energy, wind energy, biogas.

RESUME

Les exigences croissantes pour la qualité de l’eau potable et le traitement des eaux usées engendrent une consommation énergétique de plus en plus importante pour faire fonctionner les systèmes de traitement. Conjointement, suite au *Grenelle de l’Environnement*, la loi française fixe l’objectif de 32% pour la part des énergies renouvelables d’ici 2030. Ces dernières sont ainsi mises en avant comme alternative durable pour la production et l’économie d’énergie dans le domaine de l’eau et de l’assainissement.

Cette synthèse présente les coûts de consommation énergétique les plus importants sur les usines d’eau potable et d’assainissement. Dans un second temps, trois systèmes de production d’énergie renouvelable (solaire, éolien et biogaz) sont analysés d’un point de vue technique, réglementaire et économique.

Cette synthèse démontre que le panel de solutions pour la maîtrise de l’énergie est très varié. La diminution efficace et la sécurisation de l’alimentation en énergie pour les services d’eau potable et d’assainissement ne passent pas uniquement par le recours aux énergies renouvelables mais plutôt par un « mix énergétique », c’est-à-dire consommer moins, en optimisant les besoins énergétiques, et consommer différent, avec les énergies renouvelables par exemple.

Mots-clés : Energies renouvelables, production d’eau potable, station d’épuration, eau potable, eaux usées, boues d’épuration, énergie photovoltaïque, énergie éolienne, biogaz.

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INTRODUCTION: ASSESSMENT, CONTEXT AND ISSUES

Global demand for electricity keeps increasing whereas fossil fuels are running out.

In France, renewable energies account for a small proportion of all energies available. Indeed, as shown in Figure 1, 75 % of French electricity is generated by nuclear plants. Wind energy, photovoltaic energy, and other sources of renewable energies (except for hydroelectricity) account for less than 5% of the total production.

Despite this low proportion, France is one of the largest producers of renewable energies in Europe, with a primary production close to 25 Mtep (1 tep = 11 630 kWh) in 2013. In 2014, France was the second-largest producer of renewable energy after Germany (figures unpublished for 2014) (Ministère de l'écologie, du développement durable et de l'énergie, 2014a).

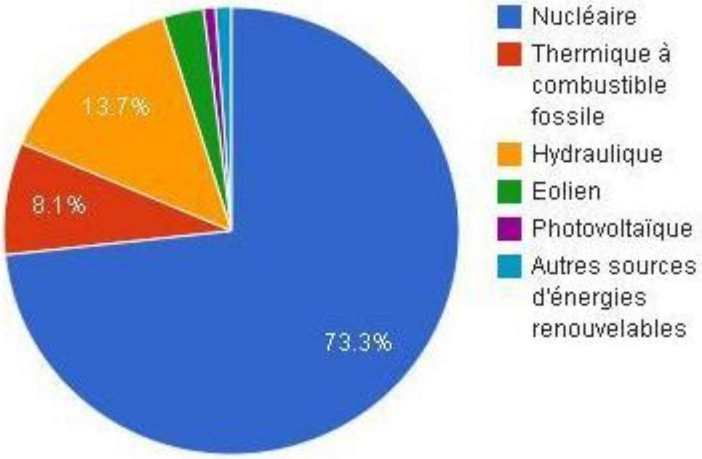

Figure 1: Share of different energy sources in the French electricity production in early 2014

Source : La Tribune, 2014

As part of the energy transition supported by the Ministry for the Environment, France first set an average renewable energy consumption target of 23% by 2020. More precisely, the objectives were different according to the sector:

- 33% for heat (biomass, solar, renewable part of waste),
- 27% for electricity,
- 10,5% for the transportation network.

To achieve this goal, the first step is to reduce electricity consumption, and the second one consists in developing different methods of producing renewable energies (Ministère de l'écologie, du développement durable et de l'énergie, 2014b).

Furthermore, the energy used by drinking water and sanitation services often account for the most important costs (Kessler et Raymond, 2009). Moreover, because of higher standards and quality requirements for drinking water and wastewater treatment, the consumption of electricity increases in order to be able to use sophisticated processes (Portero, 2010).

Even if the top priority is to provide an efficient treatment for drinking water and wastewater released into the environment, saving energy is becoming a topic of interest for communities and private companies in charge of water services. There are many issues, the main one being, naturally, to reduce costs, but also to reduce the environmental impact associated with the consumption of fossil fuel and the image of "sustainable development" that the communities themselves wish to convey. Added to this is the social and political issue, that is to say, the control of energy costs in order to limit their impact on the price paid by the customer.

Thus, renewable energies seem to be an efficient and economic solution, supported by the Government and promoted by the providers of renewable energy processes. What are the conditions and opportunities of this investment? What benefits do they provide for the economy and for ecology, in terms of image? What are the technical and regulatory requirements associated with the use of these energies? In the next section, this synthesis develops these aspects for solar energy, wind energy and biogas.

SITUATION ANALYSIS

ENERGY USE FOR SANITATION

The importance of having a good quality of drinking water and wastewater released into the environment involves processes that require a lot of energy. For wastewater treatment plants, in case of intensive systems (most common in medium and big cities), the main expenditure is due to the aeration of activated sludge basins and pumps (as shown in Figure 2, about 80 % of total). The more the treatment system deals with compact sludge, the more energy is consumed by cubic meter.

However, energy consumption is practically zero for extensive systems such as reed bed filters or natural lagoon systems, mainly set up in small communities, since this process is free of ventilation constraints, sludge processing and pumps (except at the entrance of the plant) (Heduit et Tabuchi, 2012).

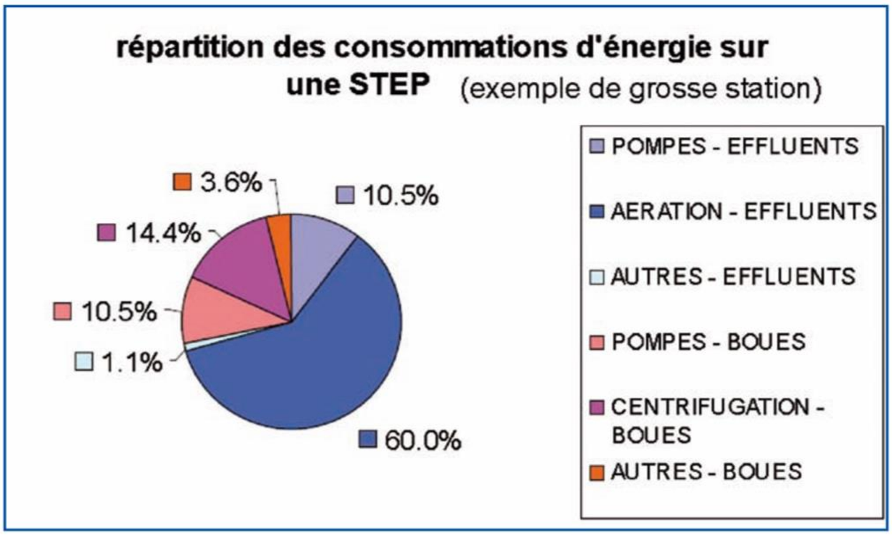

Figure 2: Distribution of electricity consumption in a large wastewater treatment plant

Source: (Kessler et Raymond, 2009)

To give an order of magnitude, with the example of an activated sludge treatment plant (most common process in France), considering a pollution load by population equivalent (PE) to 60 g BOD_5[1]/day, and a consumption of 2.5 kWh/kg of treated and transported BOD_5, the result would be approximately **60 kWh PE_{60}/year of electricity for the transport and treatment of wastewater** (Heduit et Tabuchi, 2012).

[1] BOD_5 : Biological oxygen demand for 5 days

ENERGY USE FOR DRINKING WATER

Pumping is the major source of energy consumption for drinking water treatment plants. This is the case for the Syndicat des Eaux d'Ile-de-France (SEDIF, see Figure 3), which manages the production and distribution of drinking water for 149 municipalities, corresponding to 800,000 m^3 of water every day. The operation of all SEDIF pumps consumed 193.6 GWh in 2013 (SEDIF, 2014).

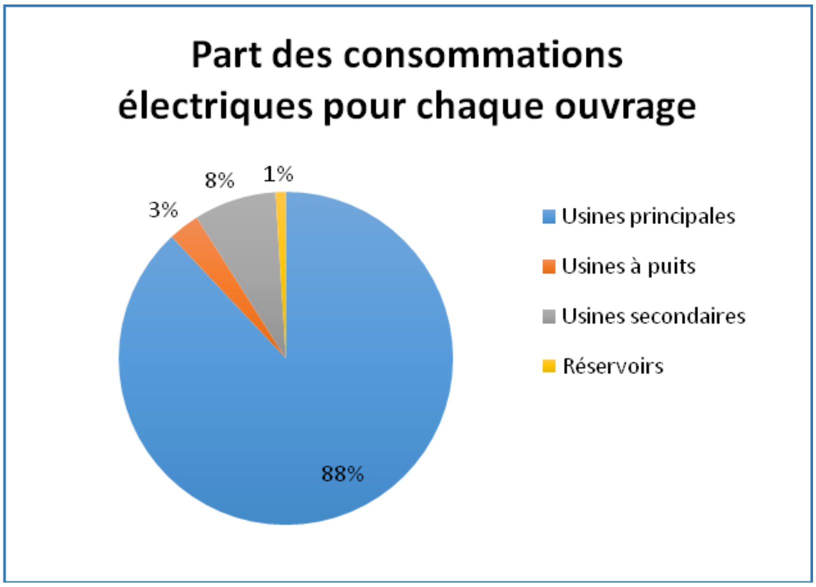

Figure 3: Distribution of electricity consumption for water supply in the Ile-de-France

Source: (Lang et al., 2013)

There are two ways of optimizing energy efficiency for drinking water plants and wastewater treatment plants. On the one hand, it is possible to reduce energy consumption by guaranteeing and improving the efficiency of the treatment sector. It can be done via the optimization of the exploitation (for example, it is possible to save energy in pumping by installing pumps equipped with frequency converters (Heduit et Tabuchi, 2012)). On the other hand, plants can use alternative energies, like renewable energies directly created on site.

RENEWABLE ENERGIES SUPPORTING DRINKING WATER PLANTS AND SANITATION PLANTS

SOLAR ENERGY

The share of photovoltaic energy produced on site in the field of water and sanitation is negligible (Portero, 2014). Two outcomes are possible for solar energy: resale of electricity or consumption on site.

Conditions for resale of electricity

Following the decree of March 4, 2011, the feed-in tariff applicable to the facility depends on both the peak power of the installation and the peak power of all other facilities using the energy radiated from the sun or planned on the same building or land area. The Commission for Energy Regulation (CER) establishes the purchasing conditions for electricity produced by private producers.

EDF is forced to buy electricity from photovoltaic installations smaller or equal to 100 kWp (Kilowatt-peak) (Portero, 2014). Beyond this limit, the producer must make a tender to sell electricity. For projects in which the connection request is before 1 July 2011, the repurchase price is between 12 and 46 c€/kWh depending on the nature and power of the installation, and the use of the concerned building (EDF, 2013). We must compare this rate with EDF's direct purchase price, which is around 10 c€/kWh.

Advantages and limitations

If the initial development of solar panels, motivated by a generous buyback policy, was generally well received, investing in solar energy production is much more moderate given the gradual decrease in resale prices. Indeed, from 60 c€/kWh for contracts signed before the end of 2011, the prices went down to 27 c€/kWh at the end of 2014.

The table 1 below illustrates the evolution of feed-in tariffs of photovoltaic electricity since the beginning of 2013. In two years, the price per kWh has lost on average 0.45 euros.

Type de tarif	Type de l'installation et puissance totale		01/02/13 au 31/03/13	01/04/13 au 30/06/13	01/07/13 au 30/09/13	01/10/13 au 31/12/13	01/01/14 au 31/03/14	01/04/14 au 30/06/14	*01/07/14 au 30/09/14*	*01/10/14 au 31/12/14*
Tarif dit T1	Intégration au bâti (IAB)	[0-9 kWc]	31,59	30,77	29,69	29,10	28,51	27,94	*27,38*	*26,97*
Tarif dit T4	Intégration simplifiée au bâti (ISB)	[0-36 kWc]	18,17	16,81	15,21	14,54	14,54	14,16	*13,95*	*13,74*
		[36-100 kWc]	17,27	15,97	14,45	13,81	13,81	13,45	*13,25*	*13,05*
Tarif dit T5	Autres installations	[0-12 MW]	8,18	7,96	7,76	7,55	7,36	7,17	*6,98*	*6,80*

Table 1: Evolution of feed-in tariff of photovoltaic electricity since 2013 (c€/kWh)

Source: photovoltaïque.info, 2013

The concept of building integration is also involved in the conditions of buying back. Indeed, at the same power, energy from panels integrated into the building (meaning that the panels actually are the roof) is bought on average two times more expensive than for a simplified installation (panels just installed on the roof). Thus, the interest in the integration of solar panels to the roof starting from the design / construction of buildings is particularly relevant.

Conclusions & prospects of solar energy

The feed-in tariffs of photovoltaic electricity were particularly interesting before 2011 (especially as the contracts are signed for 20 years): purchase at 10 c€/kWh and resale at 60 c€/kWh, that is a 50 c€/kWh profit to the producer. Today, the repurchase price is divided by three, and proportionately increasing the investment payback for the same facility.

Moreover, given the energy expenditure of wastewater treatment and drinking water plants, photovoltaic energy in situ cannot cover for all energy needs alone (Heduit et Tabuchi, 2012).

Indeed, considering an average consumption of 60 kWh PE_{60}/year[2] for effluent treatment and a **theoretical production** of 100 kWh/year for 1 m^2 of solar panelling, it would take about 0.6 m^2 of solar panels per population equivalent to cover all the energy needs of a treatment plant.

[2] see paragraph « Energy use of sanitation »

Around 120 000 m^2 for an average city of 200 000 people! This calculation is underestimated because the **actual production** of the solar panel depends on the amount of sunlight and on the tilt of the panel and is necessarily less than the theoretical production. As a consequence, some treatment plants invest in larger solar surfaces off-site (for example, the Golsar plant in Germany) (Portero, 2010).

Finally, there is the often-controversial issue of deconstruction and recycling of the panels to the end of their service life. The first generation of panels will only be deconstructed within a decade.

WIND ENERGY

Wind turbines convert the mechanical energy of the wind into electrical energy, either for injection into a distribution network or directly for the needs of the station.

In order to develop the wind energy sector, the government has implemented purchasing obligation since 2000. Thus, EDF or local distribution companies must buy electricity produced from wind energy to operators who request it, at a purchase price set by decree. The incremental cost for these obliged buyers is compensated and passed on to the final clients by a contribution proportional to the electricity they consume (called CSPE) (Ministère de l'écologie, du développement durable et de l'énergie, 2014c).

The decree of June 17, 2014, fixed the terms of purchase of the electricity generated by facilities using the mechanical energy of wind. The contracts are signed for 15 years, the price was set in 2008 to 8.2 c€/kWh for 10 years, then between 2.8 and 8.2 c€/kWh for 5 years depending on the site. This rate is updated each year according to an index of hourly labour costs and an index of producer prices (EDF, 2013).

Technical and regulatory constraints in the implementation of wind energy processes

For wind turbines smaller than 12 meters, it is necessary to complete a statement of work, as specified in the article L 422-2 of the Town Planning Code. The wind implantation site is also regulated as any installation is banned within 400 m of houses (500 m in Ile-de-France), and 100 m from roads, railroads and power lines (Eolissima, 2014).

On the other hand, a wind turbine must be at least equal to 500 kW to be profitable. It starts to produce 10% of its capacity with a velocity equal to 5 m/s (or 18 km/h) (Portero, 2014).

Conclusions and future outlook

It is technically and statutorily impossible to plan a wind turbine on a treatment plant or water purification unit. As for solar energy, wind energy production in-situ cannot cover the energy needs of wastewater and purification treatment. Exceptions are partnerships with wind farms, because one wind turbine with a capacity of 2 MW can provide an average production of 4,000 MWh a year (assuming a full power operation of 2,000 h/year), that is equivalent to the energy consumption needed to process 65,000 PE effluents (considering an average consumption of 60 kWh EH_{60}/year[3]).

[3] see paragraph « Energy use of sanitation »

BIOGAS

Biogas is produced by methanogenic bacteria that live without oxygen and degrade organic matter (like sludge from WWTP or manure) in closed environment (without oxygen). The anaerobic digestion by the bacteria produces a release of gas (biogas) mainly composed of methane and carbon dioxide (Breton, 2014).

Reducing the amount of solids is the main advantage of anaerobic digestion. Indeed, the reduction of dry matter ranging from 15 to 40%, depending on the substrates, is a major argument in the choice of this technology.

There are several biogas recovery pathways (Breton, 2014; Portero, 2014) :

1- **Local consumption:** in this case, the heat produced by burning the biogas is used to heat the digesters. The benefit of this method is to reduce the volume of sludge. There remains the question of the digestates that can be valued as farm amendments.

2- **Overproduction of biogas**:

   a. If the surplus production is low, biogas is not valued, it is burned in flare (that is to say that methane is converted into carbon dioxide and water and then released into the atmosphere). This solution is not advantageous, neither from an economic point of view (the rest is lost), nor from an environmental point of view because it releases CO_2 into the atmosphere.

   b. If the surplus production is sufficient, biogas can be valued by co-generation (electricity and heat). An estimate of the energy potential of this sector leads to 55 to 60 kWh EH_{60}/year. A cogeneration system can produce (assuming an overall yield of 80%) around 17 kWh EH_{60}/year of electricity (with a yield of 30%) and 30 EH_{60} kWh/year of heat energy (with a yield of 50%) most of which is used for heating / stirring the digester. The excess heat produced can be used to increase the dryness of the dewatered sludge to achieve their self-combustibility, or valued on a district heating system, or for space heating (Heduit et Tabuchi, 2012 ; Tabuchi, 2014).

3- **Injection into the natural gas grid:**
Three regulatory texts published in the Official Journal of 26 June 2014 just changed the regulatory framework established in November 2011 that regulates the injection of biogas into the natural gas network. They change the regulations so that biogas in wastewater treatment plants can be injected into the network after processing and enrichment.

Two pioneers have already started to work on the implementation of injection biogas sector in their wastewater treatment plant. On the one hand, the program started in 2012 by the Urban Community of Strasbourg on Wantzenau station eventually aims at injecting 1.6 million m^3/year of biomethane, equivalent to the consumption of 5,000 homes in low-consumption buildings (Laperche, 2014). On the other hand, the Aquapôle treatment plant in Grenoble, which treats about 230,000 m^3 of water/day, started a modernization program in which it plans to make anaerobic digestion and biogas injections into the network of natural gas. Eventually, 10,000 m^3 of biogas will be produced per day, or 17 GWh/year, which represents the energy consumption of about 2,500 homes (Grenoble-Alpes Métropole, 2014).

The purchase prices of the injected biomethane are between 6.4 and 9.5 c€/kWh, depending on the size of the installation. At that price, we may add a bonus based on matters treated by anaerobic digestion, or 0.1 to 3.9 c€/kWh for sewage sludge (Ministère de l'écologie, du développement durable et de l'énergie, 2014d).

Advantages and constraints of methanation
Table 2 below states the technical advantages and constraints of the implementation of a methanation system. Furthermore, there are also regulatory constraints, for example, on the incineration in WWTP. Indeed, to resend electricity produced by incineration to EDF (or another buyer), it is necessary to have a thermal efficiency above than 60%. It is a virtuous energy system that requires a minimum yield (Tabuchi, 2014).

For example, a steam turbine placed on the output of the boiler has a yield of 30% when operating in good conditions. It is not enough to reach the 60% required to have the authorization to repurchase. This system needs to be supplemented with heat recovery cogeneration (Tabuchi, 2014).

Avantages	Contraintes
Réduction de la production de boues	Coût d'investissement
Stabilisation, hygiénisation des boues	Contraintes et coûts d'exploitation
Réduction des odeurs	Risques d'explosion (règles de sécurité)
Production d'énergie renouvelable et stockable	Diminution du % MV, du pouvoir calorifique
Réduction des émissions de CO_2	Siccité requise pour l'auto-combustion en hausse dans le cas d'une incinération des boues digérées
Incitation financière vente électricité renouvelable	Emprise au sol supplémentaire
Réduction de la charge organique à traiter biologiquement (décantation primaire)	Retours d'azote ammoniacal en tête
	Carence de carbone pour dénitrification

Table 2: Advantages and constraints of methanation

Source (Heduit et Tabuchi, 2012)

In conclusion, the choice and the profitability of biogas project must be studied case by case because it must take into account the environmental, economic and social aspects.

The place-based project of combined anaerobic digestion
The co-digestion (or combined methanation) consists in the digestion of sewage sludge and other waste or fermentable product in one infrastructure, like for example municipal bio-waste (fermentable household waste sorted, manure from breeding). This is a way of treating sewage sludge that remains largely unexploited in France, which is to assess the methanogenic potential of a given geographical area in order to set up a biogas plant in a strategic location.

The implementation of the project depends on several conditions:

- **deposit and quality of organic matter recoverable into biogas** (sewage sludge, grease, manure, industrial waste). Even if their methanogenic potential is low, sewage sludge have the advantage in terms of volume and organic load stability over time (Berger 2014 ; Portero, 2014). What is more, the regular and controlled addition of exogenous organic waste to the sludge (agricultural waste, fats) can increase biogas production, and therefore the share of renewable energy available (Heduit et Tabuchi, 2012).

- **local energy context**, that is to say the distance separating the project from the natural gas network, **the match between the heat demand/energy and the production**, as well as the distance of the different substrates to value. Indeed, spending on transportation of substrates to the plant must not be greater than the equivalent of 20% of the energy produced. The boundary distance is a function of methanogenic substrate potential but is estimated between 10 and 20 km (Berger, 2014).
- **valuation of digestat**: it is related to local energy context and is about identifying the needs of farmers, the proximity of major crops and possible supplier spreading plans.

Territorial methanation allows the treatment plant to overcome in whole sludge treatment, directly sold to the factory methanation. However, there is no treatment plant in France that integrates a project of territorial biogas. Existing projects mainly concern farmers.

IS ENERGY SELF-SUFFICIENCY POSSIBLE?

There is no example of self-sufficiency stations in France but some plants are widely optimized. Some representative examples of various sectors are given below.

Solar energy

Inaugurated in 2012, the Aquaviva treatment plant in Cannes has a capacity of 300,000 PE, and uses photovoltaics to reduce its energy costs. The implementation of 4,000 m^2 of solar panels, coupled, among other things, for the reuse of treated wastewater and heat recovery, allows to achieve a "carbon neutral" station (compensation for the emission of greenhouse gases) (Suez Environnement, 2014).

Wind energy

The Perth desalination plant in Australia produces up to 144,000 m^3 of water per day. It covers 100% of its energy needs thanks to a wind farm located at 200 km, through a partnership (Suez Environnement, 2014).

Biogas

Co-digestion of bio-wastes, still underdeveloped in France, has proven to be rather effective abroad. For example, in the treatment plant of Pest-South (Czech Republic), co-digestion has multiplied biogas production by three, while on the treatment plant of Gera (Germany), electricity generation has increased from 1.8 to 2.7 GWh per year (Boughriet, 2011).

The treatment plant in Pilsen, Prague, has developed another solution: the transition from a mesophilic digestion (37 °C), to a thermophilic digestion (55 °C), which has increased biogas production and power by 30%. Coupled with the improved performance of the various hydraulic components, the station reached "a level of energy self-sufficiency of 80-90%," according to Pavel Chuboda, Veolia (Boughriet, 2011).

The optimization by modulation of consumption: two examples of peak cut off energy consumption

Operators already beneficit from tariff peak / off-peak hours and will soon be able to adapt their consumption in order to reduce or even erase the costs. In 2009, ADEME started the Réflexe (réponse de flexibilité électrique / electric flexible response) program, which objective is to identify the flexible potential of consumer infrastructures in the tertiary sector. In fact, this study demonstrates that “water and sanitation services can relieve the network by modulating, delaying or stopping certain tasks without consequences on the pollution control performance and continuity of distribution” (Véolia, 2013; Humbert, 2014).

ADEME is interested in the PACA region, due to the fragility of its current power grid, and includes in its report the principles of energy flexibility suitable for the activated sludge treatment plant of Trans-Draguignan and the drinking water supply network of the city of Nice.

Specifically, the two storm basins at the entrance of the treatment plant could be used to temporarily store the effluent in order to delay treatment, thereby reducing the power demand by a few megawatts. Deferred treatment is a way of reducing the bill without reducing the electrical energy consumption (Heduit et Tabuchi, 2012 ; Humbert, 2014).

On the other hand, the supervision of the drinking water system by measuring sensors, coupled with forecasts of the power consumption of the equipment would anticipate hourly electricity demand and identify opportunities for deletion (Humbert, 2014).

In Britain, EDF develops ENBRIN[4], an innovation program and energy performance for the years 2010-2015, which aims at encouraging energy conservation in Britain to help secure the power supply to the region.

In partnership with Veolia, the experience was life tests of "erase" in two treatment plants (Cesson Sevigne and Saint-Malo - 35) and two drinking water plants (dam Rophemel - 22 - and Muzillac - 56). This experiment consisted in lowering the power demand by 1,600 kW for the four selected sites, the equivalent of the average power required to power 2,000 homes simultaneously (EDF, 2011).

This principle of electrical peak cut off can even generate gains for drinking water supply or sanitation equipped with a renewable energy system. Indeed, the local use of renewable electricity or resale during peak hours respectively ensures electricity supply for contingencies and/or generate profits by selling renewable electricity to EDF at the "peak hours'' price.

Thus the electrical peak cut off combines the following benefits: farmers can optimize their energy bill and this process allows to reduce greenhouse gas emissions. In France, water treatment plants and drinking water treatment plants are many, which requires an energy audit to be carried out on all plants, for optimization and modulation of their consumption.

[4] ENBRIN : Energie Bretagne Innovation

CONCLUSION

In response to a growing energy demand in the field of water and sanitation, the industry and the policy makers have had to promote innovations and alternative production and consumption methods in order to ensure power supply without increasing costs drastically. Solutions for energy saving are many, and renewable energies are just some of the solutions ensuring the power supply.

Solar panels and wind turbines located on site cannot be a significant power production regarding the needs to be covered. However, investment in wind or solar farms ex-situ can be a solution to cover a larger portion of their consumption using renewable energy.

The profitability of the biogas sector mainly depends on the capacity of the treatment plant and its effluent treatment mode. The choice of the establishment, of the sludge digestion and the valuation of biogas depend on technical, economic and social constraints that take into account the local context.

There is no "turn-key" solution applicable to all stations. Nevertheless, we must move towards an energy mix to optimize the operating costs of drinking water and sanitation operation services. Indeed, the best examples of electricity consumption reduction (or energy self-sufficiency) are wastewater treatment plants or drinking water plants that chose to act at several levels in the treatment system. Performance improvement of equipment, staff training, consumption modulation and use of alternative energy sources will not go one without the other in the optimized and controlled management of energy consumption.

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