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# ANALYZING TECHNICAL AND ECONOMIC SUITABILITY OF RENEWABLES OVER WASTEWATER TREATMENT PLANTS / AN APPROACH CONSIDERING ENERGY POLICES AND THEIR IMPACTS

PRESENTA:

**ANDRÉS YAOTZIN JIMÉNEZ TORRES**

**DIRECTORES DE TESIS:**

DR. LUIS ARMANDO BERNAL JÁCOME / DR. PROF. ING. RAMCHANDRA BHANDARI

**ASESOR:**

DR. JUAN MANUEL IZAR LANDETA

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## Dedicatoria

Esta tesis está dedicada con todo el cariño a mi hermano y amigo Edgar **Ave**.

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# Analyzing technical and economic suitability of renewables over wastewater treatment plants

## An approach considering energy policies and their impacts

**Thesis Project**

**Andrés Yaotzin Jiménez Torres – 11103503/096778**

**Dr. Prof. Ing. Ramchandra Bhandari – ITT supervisor**
**Dr. Luis Armando Bernal Jácome – PMPCA supervisor**
**Dr. Juan Manuel Izar Landeta – external supervisor**

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# Analyzing technical and economic suitability of renewables over wastewater treatment plants / An approach considering energy polices and their impacts

## Research problem

Something that typifies waste water treatment plants is their exhaustive and non-stopping characteristics, which in turn is reflected in high energy requirements and in most cases are satisfied by electricity. Unfortunately, electricity as an energy source is expensive. From an economic perspective, high energy costs have two undesirable effects: firstly, the increase of operational expenses and secondly, the reduction of plant's competitiveness This may represent difficulties if plants cannot generate enough income to properly cover their operational costs. Moreover, expensive costs of operation can be even more problematic for plants that depend entirely on scarce governmental budgets or delayed payments, because their services and operation cannot continue if their bills are not paid on time. One option for such plants to reduce energy dependency and costs is the implementation of renewable energies; which can partially or completely satisfy their demands. In Mexico, the current electricity law is generating radical changes over the entire energy market, representing opportunities and challenges for everyone. On one hand, good opportunities can be foreseen for those ones with the ability to exploit their own infrastructure and goods to produce clean electricity, mainly because renewable and clean energy technologies will be highly benefited by the incoming electricity law; but on the other hand, the new market may bring unpredictability over electricity prices, which may interfere with their operation in the future.

## Justification

The new electricity industry law was enacted in Mexico in 2014, changing the rules for the entire electricity market and opening new structures of the market for private intervention. For the case of renewables, the previous market was opened with some limitations before the law appears, but now, the new law is considering establishing an obligatory portion of them into the national electricity mix, with the intention to promote their usage in the years to come. The industrial sector, as one of the biggest electricity consumers, has exceptional attention to the electricity sector; especially because price risings are perceived as operational risks, pushing decision makers to find options to stabilize them. In response to the economic pressure electricity costs represent, some companies with enough economic capacity have seen in renewable energy an opportunity to reduce electricity expenses. Nevertheless, the lack of incentives for renewable energy implementation in the past (lack of economic viability, awareness among users and high subsidized energy prices), has created a gap, leading uncertainties for investors and companies to go further into renewable energy technology today. This unfortunate situation may not be negative in all senses, this, because this gap may well symbolize an opportunity for research projects that divulge tools for renewable energy implementation.

In Mexico, due to the type of technology, a considerable portion of wastewater treatment plants has high energy demands, being reflected on major operational costs. Such high expenses are perceived by private and municipal wastewater treatment operators as an operational risk; in case of no payment or founding. In addition, an increase of water usage in recent years has put additional pressure onto the sector because demands are gradually increasing with population growth and its escalating life quality. Therefore, a research addressing renewable energy implementation and adaption, with regard to the new law and focused on wastewater treatment plants problems, might help decision makers to take decisions with respect to electricity in a better way, especially for those who are struggling with economic factors.

## Objective:

Analyze the applicability of renewable energy technologies over an existing plant and its processes, taking into account its own technical and economic characteristics, with regard to the new electricity industry law in Mexico and towards a level of energy and economic independence.

Particular objectives:

- Analyze the energy consumption scale and power potential for each wastewater treatment process, in order to evaluate the likelihood to obtain or apply clean energy.
- Detect the best renewable energy technology options for wastewater treatment plants and evaluate the most suitable ones for the selected plant, considering its own energy requirements and characteristics.
- Generate an economic strategy, taking into account the current electricity legislation, with the aim to improve wastewater treatment in terms of energy and economic independence.

## Hypothesis

Applied renewable energy supported by economic models, as generation for self-consumption or cogeneration, has the potential to partially or completely satisfy wastewater treatment energy demands, whenever energy policies ensure interconnection and economic interaction with the market. The new enacted electricity industry law has developed tools and set proper conditions, in agreement with the water sector, to increase renewables usage amongst public and private operators into the wastewater treatment service segment; allowing all kind of actors to satisfy their energy requirements, whether or not earn directly from their services, in an economical, technical and sustainable way.

## Methodology

To generate a technical and economic suitability analysis, the context where a project or case study must be analyzed. In this sense, the present work goes analyzing thoroughly the wastewater and energy sectors, in order to gather enough information to sustain the assessment. Besides, a parallel analysis over the policy structure of the already mentioned sectors is made; this, with the intention to reveal the rules of performance and how them can drive or detract the implementation of projects. To make it possible, some calculations and models are necessary. For the technical analysis, a pre-assessment of resources is developed to select what would be the potential technologies to be implemented into the plant and, once having this information, a technology search into the local market is necessary to further continue with the technical evaluation and design. The technical design and assessment is assisted by software as well as common formulas performed in spreadsheets. Something similar happens with the economic analysis where different economic evaluation methodologies are applied. To better understand what the project might do for the wastewater treatment plant, the present work performs a simulation of the power plant attached to treatment one. This simulation model finally gave the key data to decide which of the proposals is the best to be supported, towards energy and economic independence. The present section does not describe completely the methodology employed, for that, each chapter and section describe specifically the method employed or make reference in which part is specified.

# Wastewater treatment - 1st chapter

## Introduction

Wastewater treatment (WWT) processes have been and can be analyzed since different approaches; technologically, in their life cycle, related to the amount and type of energy they use and their pollution potential amongst others. In this case, the main purpose of this work is to analyze focusing on technical and economic aspects, the implementation of renewable energy technologies over wastewater treatment plants (WWTPs). To do so, the selection of one location it was necessary; being the city of San Luis Potosi in Mexico the carefully chosen one. The reason of selecting such city and one of its WWTPs is not randomly, it is motivated by current economic difficulties some municipal plants in the state face. During the last decade, the Mexican government discover a considerable portion of municipal plants was not working at their nominal capacity; the reason, the high operation costs related to electricity and the incapacity of municipalities to bear with such compromises. As an example of this, along 2008, the municipality of Acapulco[1] despite of counting with enough treatment capacity, it could not operate properly due to the high operational costs (electricity). To cope with this, the government made an enormous effort in order to incentivize WWTPs operators to turn on plants and sum up the rising initiative of wastewater treatment (from 40 to 60% of the national average). To date, due to the low wastewater treatment achievement, the government continuously motivates the sector by several programmes. The statistics say: treatment is still low (46%) and the untreated wastewater, alone, causes about 68% of the GHG emissions accounted by the sector. In the state San Luis Potosi there are 50 WWTPs and at least 3 of them faces problems to pay their electricity and treat water.

## Water sector in Mexico

Mexico counts with 37 big hydrologic regions throughout the country which contains 731 natural watersheds with superficial water availability and all of them are put together into administrative divisions called as *hydrologic administrative regions* (HARs)[2], which serve for water management and administration (Maass-Moreno 2015). The number of regions is 13 in total and they are

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[1] Acapulco is one of the biggest maritime ports and tourism spots in Mexico.

[2] HAR is a national administrative division which groups several watersheds and municipalities; is considered the basic managing unit in terms of water usage. Although this unit is the major authority about water issues into the region, in practice, the administration relays on municipal authorities with the support of local HAR offices (CONAGUA 2015).

important in terms of economic and strategic aspects because through them is how the government motioned the entire water sector. Nevertheless, the operational part of water services (potable water, drainage and water treatment) usually relay on municipalities – despite the administrative divisions – and it is also common that operational entities called *water operators* are created by municipalities to administrate the sector locally (CONAGUA 2015).

Administratively, the city of San Luis Potosi (CSLP) is part of the seventh HAR "Cuencas Centrales del Norte"; hydrologically, is in the "*El Salado*" region; and geographically, is located in the western part of the state of San Luis Potosi, being the capital and the biggest city (772,604 inhabitants). The Cuencas Centrales del Norte, where the city is located, is the second driest region in the country with 430 mm per annum (see Figure 1). For the case of the municipality, its normal precipitation (372 mm) in comparison with the national average (760 mm) is very low, taking place the majority of it during July and September (CONAGUA 2015; SMN 2010; CONAGUA 2014a). In some occasions, such precipitation patterns have caused overcapacity problems in drainage[3] and wastewater treatment systems, forcing the releasing of untreated mixed water (rain and wastewater) towards water bodies or agricultural lands (Ávila n.d.). Additionally, the area also suffer short strong droughts, which are categorized as *anomaly* and *mid,* and long term droughts during the driest month (May) (SMN 2010; CONAGUA 2013; CONAGUA 2015). This means, the municipality faces extreme weather conditions (extreme droughts followed by intense rains) within a short period of time (about 4 months).

Due to the city is located in a closed basin and counts with near one million inhabitants, the drought aspects mentioned before are stressed even more when water consumption brakes into the scene. Before 2013, the city's consumption was around 3 $m^3$/s and the supply usually was covered by three damns (3%) and underground water (97%)[4]; being clean water totality endeavored to human consumption and related services into the city. Therefore, the only available water for agricultural needs was untreated wastewater (Peña-Ramírez 2013). Furthermore, the aquifers that supply the city have been declared overexploited, forcing to go deeper to extract the liquid and separate the minerals which are mixed with depth water (CONAGUA 2013; Olvera 2016b; Peña-Ramírez 2013). To date, an aqueduct coming from a near state (Guanajuato) has been recently opened with a supply capacity of 1 $m^3$/s and with intention

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[3] The type of drainage most common in Mexico is mixed (rain and wastewater) (CONAGUA 1997; Sturm n.d.)

[4] Levels of water today are very deep in the valley of San Luis, increasing considerably the amount of energy to extract the liquid (Peña-Ramírez 2013).

to reduce underground water extraction and its consequences[5]. However, the state water commission reports, underground water depletion cannot be stopped until all WWTPs will be fully operative, treating about 98% of the metropolitan wastewater (2.5 $m^3/s$) (Peña-Ramírez 2013; INTERAPAS 2015; Ruiz 2016).

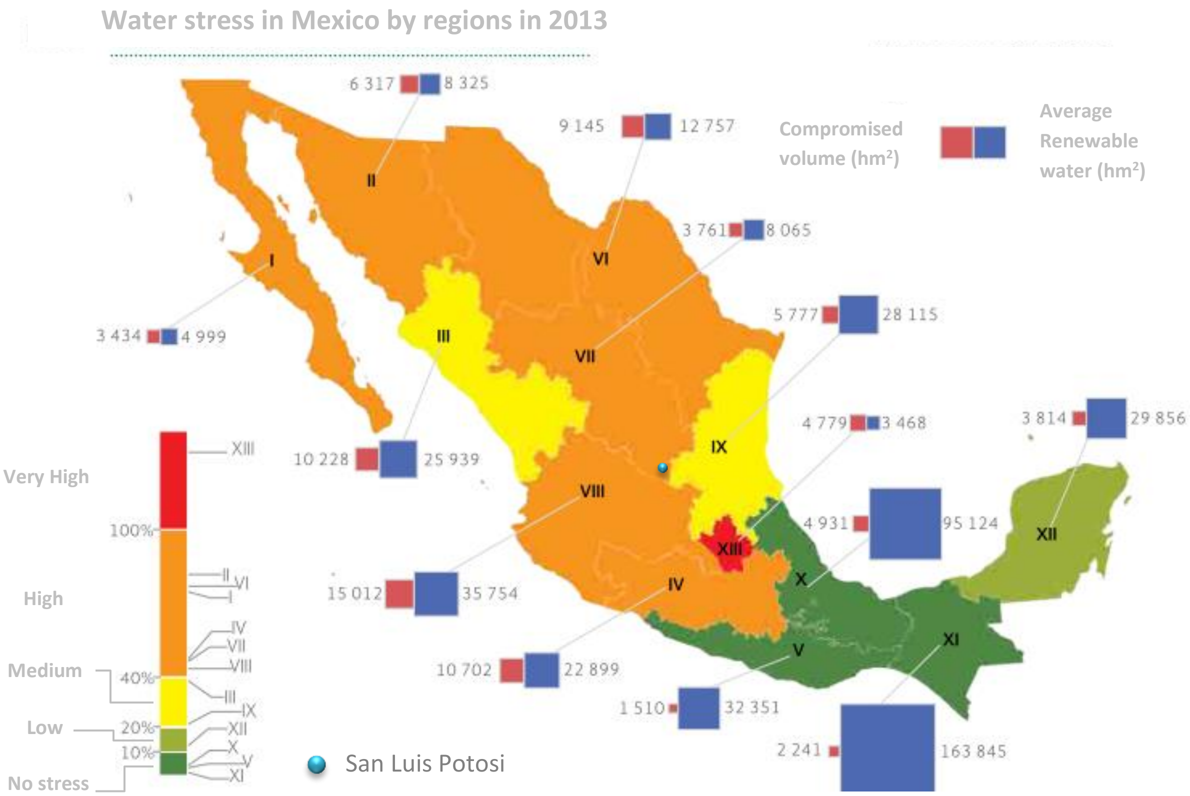

**Figure 1. Water stress** (CONAGUA 2015)**.**

## Wastewater treatment

Wastewater is a byproduct of some human activities associated with water usage. Once water is used it is disposed to the sewer, containing a complex mix of inorganic and organic pollutants which are dissolved or floating into the water. The type and level of pollutants depend on its origin[6] and the content in wastewater is commonly measured by *mg/lt*. When the level of

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[5] Nowadays, deep water extraction in the basing of San Luis Potosi is causing several health problems to the population. The reason is, water in that depth contains high levels of mineral salts and specially flour that affects heavily humans (Peña-Ramírez 2013).

[6] Wastewater can be classified as municipal (domestic), industrial or commercial (Ávila n.d.; Sturm n.d.).

pollutants exceed allowed levels into water is considered very toxic[7] to be discharged into water bodies or onto the ground. Therefore, it is necessary to treat it before to be released.

The composition of wastewater is determined by the quantities of the different types of dissolved or floating solids (DOP 2013; Ávila n.d.) and this composition must be studied by WWTP planners in order to characterize the inflow[8] and set the keystones of the future treatment. Different chemical and physic characteristics of solids, as well as variations of the composition and concentrations of wastewater[9] are considered during a certain amount of time as part of this very first step, creating enough statistical information for equipment searching (DOP 2013). This information is very important for this particular project because at this stage the capacity of the plant is somehow fixed and the type of treatment can be enclosed, resulting in equipment and machinery needs, which in turns might be reflected into a load profile of the plant.

## Methods of treatment

There are three categories of processes that happen in a general manner throughout wastewater treatment. Such processes are not necessarily to be consecutive one from another or in a specific sequence; they can be mixed along the progression of treatment and meanly depends on the specific design of the plant. However, in some extend, the following order depicts the sequence water can pass through a treatment plant.

- Physical processes: Those processes in which the major force of treatment is physical and are virtually exclusive for a pretreatment or tertiary treatment.
- Biological treatment: These types of processes are those made by microorganisms along the treatment, which aim to reduce and/or eliminate organic and non-flocking mater.
- Chemical processes: Processes which use chemical reactions to eliminate water pollutants. These types of processes can happen in parallel with physic and biologic methods (Ávila n.d.; Ramírez & Vázquez 2012b).

## Types and level of treatment

There are three main levels of wastewater treatment, but this does not mean one plant should have all levels of treatment. The first pace commonly taken is a pretreatment, which is necessary to get rid of garbage and regulate the flow before the primary level starts; in the first treatment

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[7] Water pollution is considered when the concentration of certain impurity exceeds regulated levels of the local rule. Most of the time such rules consider the capacity of nature to set the levels (Ávila n.d.).

[8] Inflow characterization is the first step of a WWT plant design (DOP 2013; WHO 2015).

[9] Measurements and continuous fieldwork are needed along certain time in order to consider fluctuations regarding climate conditions, seasons and wastewater emitters' behavior amongst others (DOP 2013; WHO 2015).

stage the PH level is adjusted and the floating organic and inorganic matters are removed; the secondary level is used to remove colloidal or dissolved organic matter; and the tertiary is the one that finally takes away other dissolved matter[10] (CONAGUA 2015; DOP 2013).

The next figure shows the treatment steps with their respective objectives and sequence.

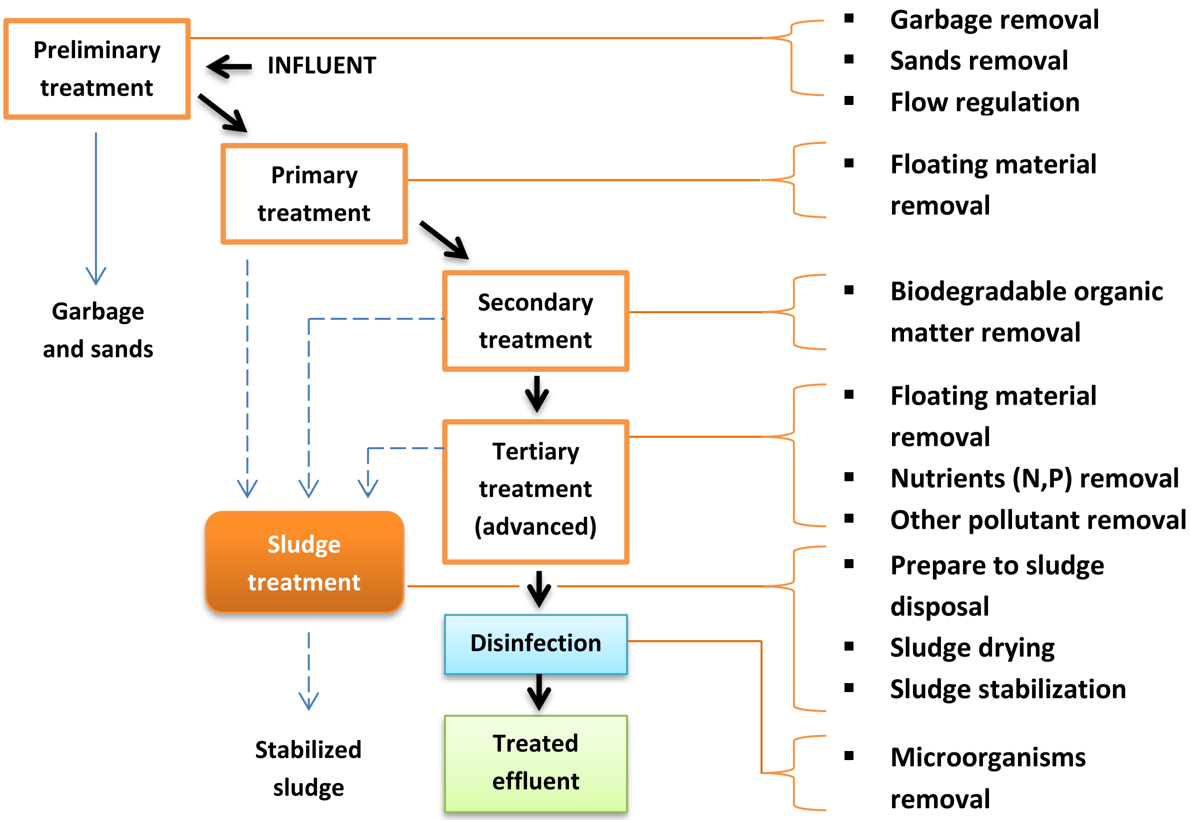

Figure 2. Wastewater treatment processes and their objectives (DOP, 2013)

## Wastewater in Mexico and San Luis Potosi

In Mexico, water quality and wastewater composition is measured by three parameters: Biochemical oxygen demand in five days ($BOD_5$); Chemical oxygen demand (COD); and the Total suspended solids (TSS). The first two parameters reflect the amount of organic matter into the water, commonly coming from wastewater either each of them indicates different water compositions. On one hand, $BOD_5$ indicates the amount of biodegradable organic matter; and on the other hand, COD measures the total amount of organic matter into the water. Major values of COD might indicate wastewater coming from non-municipal discharges, such as commercial or

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[10] Dissolved matter includes: gasses, organic or synthetic substances, ions, bacteria and virus (CONAGUA 2015; DOP 2013).

industrial. The third one (TSS) measures the concentration of all solids contained into wastewater by quantifying solids being retainable by specific size filters (CONAGUA 2015).

To provide water treatment the country counts with 2,287 municipal and 2,617 industrial WWTPs, covering between 75 to 85% of sanitation. Currently, the amount of wastewater generated in Mexico by urban and rural centers is 7,260 $hm^3$/yr (230.2 $m^3$/s) and just near to 92% is collected by drainage systems, from where 50% is treated; meaning just 46% of the whole generation is treated. For the case of non-municipal wastewater, the situation is even worst; 6.63 thousands of $hm^3$/yr (210.26 $m^3$/s) are generated and just 28% of this wastewater is treated (see Table 1) (CONAGUA 2013; CONAGUA 2015).

| **Concept** | **Amount** ($m^3$) | **Unit** |
|---|---|---|
| Municipal wastewater (urban and rural) | | |
| Wastewater generation | 7.26 or 230.2 | Thousands of **$hm^3$/yr** or **$m^3$/s** |
| Wastewater collected | 6.66 or 211.1 | Thousands of **$hm^3$/yr** or **$m^3$/s** |
| Wastewater treated | 3.34 or 105.9 | Thousands of **$hm^3$/yr** or **$m^3$/s** |
| Generation | 1.96 | Mill of tons of **$BOD_5$** |
| Collected from sewage | 1.80 | Mill of tons of **$BOD_5$** |
| Removed from WWTPs | 0.73 | Mill of tons of **$BOD_5$** |
| Non-municipal wastewater (including industry) | | |
| Wastewater generation | 6.63 or 210.26 | Thousands of **$hm^3$/yr** or **$m^3$/s** |
| Wastewater treated | 1.91 or 60.72 | Thousands of **$hm^3$/yr** or **$m^3$/s** |
| Generation | 9.95 | Mill of tons of **$BOD_5$** |
| Removed from WWTPs | 1.30 | Mill of tons of **$BOD_5$** |

**Table 1. Wastewater numbers in Mexico** (CONAGUA 2015)**.**

Regarding methods and types of treatment, it has been found in Mexico there are three key types with different system technologies, mainly occurring in secondary and tertiary treatments in which biologic processes are applied. Such technology can be classified as follows (see Table 2) (Ramírez & Vázquez 2012b).

| Type of treatment | System of treatment (Technology) |
|---|---|
| **Aerobic** | Biological discs |
| | Biological filters |
| | Oxidation ditch |
| | Activated sludge |
| | Aerated lagoons |
| | Stabilization ponds |
| **Anaerobic** | RAFA |
| | IMHOFF tank |
| | Septic tank |
| **Combined** | Enzymatic reactor |
| | Dual |
| | Wetland |

**Table 2. Types of wastewater treatment and their systems in Mexico** (Ramírez & Vázquez 2012b)

From the processes mentioned before, *the most common* – considering units of wastewater treated in municipal plants – are *activated sludge* and *stabilization lagoons*; accounting themselves about 70% of the whole generation (see Figure 3) (CONAGUA 2015).

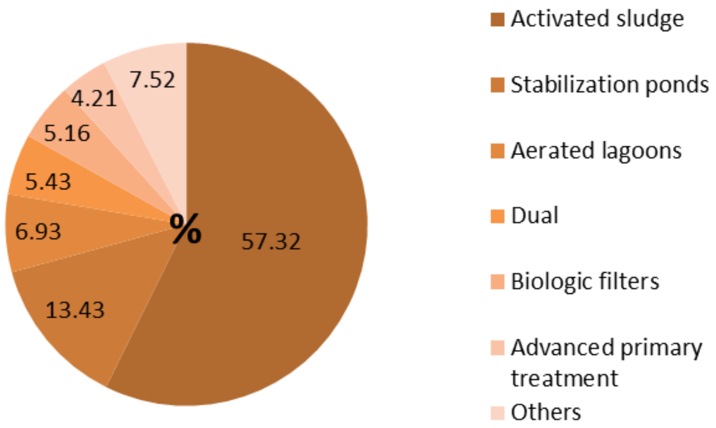

**Figure 3. Main processes of wastewater treatment in operation in 2013** (CONAGUA 2015)**.**

Regionally, the administrative region accounts itself 146 municipal plants, with an installed capacity of 6.71 $m^3$/s and treating 5.43 $m^3$/s (CONAGUA 2015). From that number of plants, a big portion (38 municipal and 50 industrial) is operative just in the state of San Luis Potosi, nevertheless, the installed capacity (0.82 $m^3$/s) is very low in comparison to the region average. In the last decade, the city of San Luis Potosi and the conurbation zone of the neighboring municipality (Soledad de Graciano Sanchez) generated together about 269,574 $m^3$ per day, in which the most common pollutants were fats, oil and coliforms (AA/UASLP 2010). The next table shows such generation.

| **2000-2010** | | |
|---|---|---|
| Generator | Industrial wastewater | Domestic wastewater |
| San Luis Potosi | 147,945 m$^3$/d or 1.71 m$^3$/s | 59,645 m$^3$/d or 0.69 m$^3$/s |
| Soledad de Graciano Sanchez | 55,228 m$^3$/d or 0.63 m$^3$/s | 6,700 m$^3$/d or 0.07 m$^3$/s |
| 2015 | | |
| Generator | Industrial and domestic wastewater | Wastewater treated |
| San Luis Potosi | 225,924 m$^3$/d or 2.61 m$^3$/s | 167,184 m$^3$/d or 1.93 m$^3$/s (74%) |
| Soledad de Graciano Sanchez | | |

**Table 3. Wastewater generation and sanitization in the city of San Luis Potosi** (AA/UASLP 2010; INTERAPAS 2015).

To treat wastewater in the city the government employs mainly three municipal plants[11] which treat 1.56 m$^3$/s, while the remaining portion (0.37 m$^3$/s) is treated by other 48 private plants. The water generated by these plants is majorly engaged to industrial processes and just a small share for green areas irrigation (INTERAPAS 2015).

During the last decade, the federal government recognized low levels of treatment in Mexico (40%), also accepting the danger untreated wastewater discharges represent to water bodies. At the moment to explore the origins of the problem, the government found: many WWTPs were switched off because municipalities could not pay operation costs (mainly electricity ones). One example is the municipality of Acapulco[12], that in 2008, despite had enough water treatment infrastructure could not treat water because the inability to pay. Since that, the government saw the need to create financial support for water operators and municipalities, revealing the structural crisis the sector was suffering. The resultant subsidies were backed by governmental financial institutions as BANOBRAS (Calderon 2008).

## Water rights and finance

In Mexico, all people and legal entities have the right to access water and water services as long as they pay for them and such usage, as well as the discharge, generates rights and duties for all

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[11] The three main municipal plants in the city are tanque tenorio, 1.05 m$^3$/s; Norte, 0.40 m$^3$/s and Tangamanga I, 0.11 m$^3$/s (INTERAPAS 2015).

[12] The city of Acapulco has one of the most important ports within the country and also is one of the best touristic spots of the state of Guerrero.

equally; this is stated in the law of federal rights. Regarding to discharge rights, it is also issued in the law that such privileges have costs and those costs are driven and influenced by the type of vulnerability of the site, being three types (A, B and C[13]). Therefore, the costs of discharging are set considering the damage sanitized or non-sanitized wastewater might cause. Additionally to this, wastewater releasing fees are also sized in relation to the volume of discharge and waste product content (CONAGUA 2015).

Water usage and services payments are designated by law to be collected by CONAGUA and municipal operators. In 2013, the collected amount of discharging rights represented just about 2% of the total CONAGUA's income, which is relatively low in terms of economics and environmental risk. To date, CONAGUA is facing a financial deficit in its operation; such as in 2013, when the collected income just represented 35% of the expended budget. Regarding municipal water operators, a study made by CONAGUA in 2013 shows the dissimilarity between billing and payment is alarmingly high. The deficit of payment accounts above 30%; meaning just only 70% of bills are paid by users and the remaining percentage escalates the financial deficit the government commonly borne[14] (CONAGUA 2015). This could be a reason that pushed water operators to close wastewater treatment plants in the past. To cope with this problem, sanitization in Mexico is constantly supported by the federal government in order to achieve more coverage and to do so, the government has created several programmes[15] and inter-alliances that have a budget of 376 mil euros[16] (about 20% of the water sector expenditure) (CONAGUA 2013; CONAGUA 2015; CONAGUA 2014c).

Water tariffs are usually set by municipalities and their structure depends on local policies rather a general one defined by CONAGUA; so, the differences amongst them, in terms of prices and structure, can be numerous. In general, tariffs in Mexico are increased in blocks – the more the demand the higher the price – and big part of them are compound by three concepts: fixed costs,

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[13] From A to C, the "C" receiving body type is the most vulnerable to pollution (CONAGUA 2015).

[14] The majority of the commission's budget comes from federal sources (61.9%) and the rest from other governmental levels: states share 15.8%, municipalities 8.9% and the remaining 13.3% comes from other sources (CONAGUA 2015).

[15] PROMAGUA, PROTAR and PRODDER are the main programmes that drive financial aid to WWTP in Mexico. To see more about these programmes, please, see chapter two.

[16] All monetary values in this paper are in euros (€), with actualized exchange rates of 24/02/2016. The considered exchange rates are: 1 EUR (euro) = 20 MXN (Mexican pesos) and 1.10 USD (US dollar) (BANXICO 2016a; Commodity Systems 2016).

potable water costs and sanitation costs. Regularly, fixed and sanitation costs are factorized from potable water costs.

Along the country municipalities, water operators and local legislative bodies create their own criteria to pricing water services (including wastewater treatment). Such initiatives and rules are occasionally set by regional or local laws, other times pricing methods are applied and sometimes they just appear validated by the local water committee without any price reference. As could be seen in Figure 4, sanitization costs[17]amongst municipalities are diverse and their proportion[18] with respect potable water costs has no evident rule that reveals how do they were calculated (decontamination costs range from 0% until 50%) (GEBC 2014; GEC 2015; Hillo-Municipality 2015; CCAPAMA 2015; COAPATAP 2015; CONAGUA 2015; CONAGUA 2016). Unfortunately, the manifold and not clear types of pricing do not allow watch whether the sanitation costs are being correctly charged and if the collected money is covering wastewater treatment operation costs. In San Luis Potosi, the way of pricing is not different than the mentioned before. Water prices (domestic, commercial and industrial) are set by the local parliament without any visible rule of pricing and for the sewage and treatment components; no allusion to the user category or the vulnerability types of receptive bodies is made. It is stablished that all tariffs are compound by four components: the main, which is the potable water tariff (per $m^3$); the supplementary, calculated by fractions of the main: 15% more for sewage and 20% for treatment; and finally, the taxes (SGG 2014).

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[17] Sanitation costs normally consider drainage and wastewater treatment cost (CONAGUA 2015).

[18] Municipalities and water operators usually fix a percentage with respect the potable water tariff for sewage and sanitization prices calculation, where no visible rule is visible, at least in the municipalities tariff papers analyzed (GEBC 2014; GEC 2015; Hillo-Municipality 2015; CCAPAMA 2015; COAPATAP 2015).

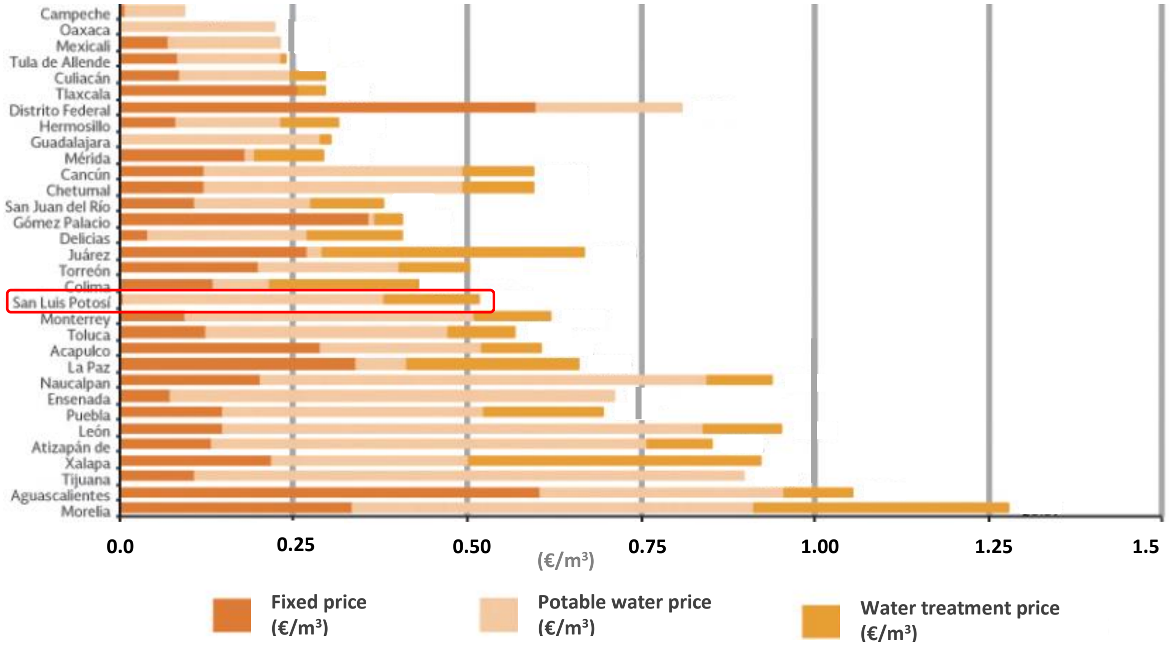

**Figure 4. Domestic water tariffs in Mexico** (CONAGUA 2013)

Based on a Global Water Intelligence report, a comparison made by CONAGUA contrasting different countries and their water prices with the results obtained in Mexico shows the country is far from what is happening around the glove. Such comparison reveals, in the year 2012, a representative Mexican tariff (Mexico City’s) was listing as one of the cheapest and its composition was made just with two (fixed costs and potable water) of the four (fixed costs, potable water, treatment and taxation) evaluated tariff components (CONAGUA 2015). Despite it is not possible to say whether the low prices in Mexico are positive or negative, the low income perceived from them and the financial deficit suffered by the entire sector in recent years suggest there is something wrong with the pricing method in Mexico and that should be modified in order to stabilize it.

## WWTPs’ evaluation (State of the art)

Into the field of WWTPs there are several perspectives to analyze their processes and performance, nevertheless, the variety of perspectives are most of the time related with two main study areas: Environmental and Economic  (Abusoglu et al. 2012; Björklund et al. 2001; Chae & Kang 2013; Devi et al. 2007; Gude 2015; Han et al. 2013; Mo & Zhang 2013; Molinos-Senante et al. 2012; Molinos-senante & Hernández-sancho 2014; Molinos-Senante et al. 2010; Rodriguez-Garcia et al. 2011; Wu et al. 2015). Since economic analysis are quite common to be applied to any production process or sector is not surprising to found this perspective in recent reports; however, the environmental one has seemed to attract a lot of attention recently. Some authors mention WWTPs have been environmentally studied since the last two decades, and this has been motivated by the rising environmental concern and the Global Warming Potential (GWP) some processes into the treatment have (Rodriguez-Garcia et al. 2011).

Regarding environmental perspectives, one of the most appealed methodologies is the Life Cycle Assessment (LCA), which is a perspective of "cradle-to-grave" of products and services (Saic, 2006), in which plants are evaluated as systems. In this sense, Houillon & Jolliet (2005) studied the best way to treat wastewater sludge from a LCA perspective, considering energy and the GWP. The comparison confronts *six processes* applied for wastewater urban sludge treatment, arranging them in two main '*categories*'; 'new *processes'* (wet oxidation, pyrolysis and incineration in cement kilns) and '*common European processes*' (agricultural spreading, specific incineration and land filling). In Thailand a research addressing biogas production from cassava byproducts (wastewater, pulp and peel) evaluated a LCA in WWTPs that convert biomethane into an upgraded biogas for running automobiles (Papong et al. 2014). Similarly to this one, but in China, a study developed a comparison between WWTPs producing bio-oil and non-oil producing plants (Vera et al. 2015). As could be noticed, LCA could be very flexible in terms of analysis and it is highly advantageous for analyzing supply, processes and external ends of a system.

Continuing with environmental analyses but associating with different perspectives, some authors started to link environmental sustainability with economics (Venkatesh & Elmi 2013; Rodriguez-Garcia et al. 2011; Molinos-senante & Hernández-sancho 2014). One of them is Rodriguez-Garcia et al (2011), who analyzes a group of WWTPs and starts to differentiate old technologies and their "end-of-pipe" approach from the more environmental friendly ones. Their environmental-economic assessment classifies 24 plants[19] into six plant typologies and describes the performance of wastewater treatment technologies in the studied plants, providing tools and economic information to decision-makers. With respect to the environmental part, the authors focused their

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[19] The 24 plants mentioned in the study were designed for over 50,000 inhabitants. The first group pertains a region with an rainfall average of 1,289 mm/y and second group pertains a dryer zone with 405 mm/y in Spain (Rodriguez-Garcia et al. 2011).

analysis on the operation[20] stage because they consider such stage is more relevant in terms of GWP rather than other stages of the plant´s lifespan; this, despite a big portion of the GWP (25-35%) was detected for the construction phase. About the operation phase[21], the study found operational issues become relevant for the economic and environmental assessment because process and technology, which are directly related to operational costs, determine energy demand of plants. Regarding operation costs, it was found: plants share a common costs configuration during their lifespan: energy (26%), staff (35%) and others (39%); the importance energy costs have over operation ones is high and electricity demand is utterly related to treatment techniques. Some other '*concepts'* appear into the scene and are very interesting, for example: the WWTPs '*energy and water autarky'* mentioned by Gude (2015), the '*energy-water nexus*' mentioned by the World Energy Council (2010) and the '*energy independence*' studies (Chen & Chen 2013; Khiewwijit et al. 2015; Chae & Kang 2013)[22]. Regarding to the latter, it is important to mention such studies are majorly based on renewable energy assessment because such technologies are considered advantageous in those aspects, which is very remarkable for this particular work.

Over the economic analysis of WWTPs, there are studies (Abusoglu et al. 2012; Molinos-Senante et al. 2010) that talk about hidden economic aspects and cost-benefit analyses (CBA). The latter introduced by Molinos-Senante et al. (2010) considers the non-marketable and invaluable benefits coming from wastewater treatment and presents the CBA as decision making tool that considers all priceless benefits, referring to environmental ones, which are not being accounted properly in terms of price. The idea is internalizing environmental externalities (called shadow prices) into WWTP accounting. To do so, the proposed CBA considers all market calculating cost as well as environmental externalities[23] for the computation of performance; based on the shadow price estimation methodology. Another type of economic analysis intends to mix thermodynamics and economic theories to assess WWTPs performances, with the aim to provide plants an adequate

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[20] The authors consider "primary, secondary, and tertiary treatments (when present); final discharge of the treated effluent; as well as the sludge treatment and its final disposal" for the environmental impact associated with the operation of the plant (Rodriguez-Garcia et al. 2011).

[21] The operation stage costs are divided mainly in energy, staff and others (Rodriguez-Garcia et al. 2011).

[22] Cfr. (Björklund et al. 2001)

[23] "Wastewater treatment can be considered a production process in which a desirable output (treated water) is obtained together with a series of pollutants (organic matter, phosphorus, and nitrogen, etc.). Contaminants extracted from wastewater are considered undesirable outputs" or externalities "because if they were dumped in an uncontrolled manner they would cause a negative impact on the environment" (Molinos-Senante et al. 2010).

cost model based on thermodynamic principles, such as exergy[24]. Such study claims to be more practical than conventional economic and energy appraisals (Lamas et al. 2010).

## Energy use in WWTPs

A tremendous link between water and energy exist nowadays, so broad and strong that they are vital for a wide range of operations in manifold sectors (WEC 2013; WWAP-UNESCO 2014). Tradeoffs[25] between them are discovered day by day and as a consequence more deeply researched is developed and supported. One particular reason that motion that is the growing population, which increase demands constantly and put overpressure on such noticeable resources (WWAP-UNESCO 2014; Bazilian et al. 2011). A report made by WWAP-UNESCO in 2014 shows the required amount of energy to generate 1 $m^3$ of potable water and it is interesting to see all techniques to obtain water, including in river water harvesting, symbolize at least some units of energy. For the case of wastewater treatment[26] energy consumption per unit ($m^3$) is the second highest in the list with a range of 0.62–2.5 kWh/$m^3$ (See Figure 5).

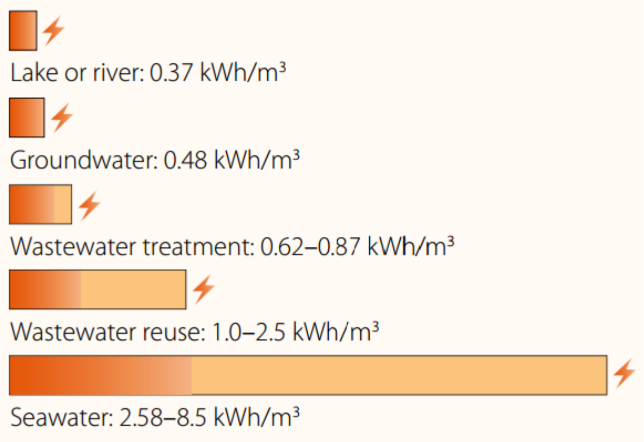

**Figure 5. Water harvesting technologies and their energy load,** (WWAP-UNESCO 2014)

Some authors have taken the energy to water topic to develop researches with their own perspective (Rodriguez-Garcia et al. 2011; Khiewwijit et al. 2015; Gude 2015; Rojas & Zhelev 2012; Mo & Zhang 2013; Chae & Kang 2013; Devi et al. 2007; Nowak et al. 2015). For example, Gude (2015) has mentioned the most common WWTPs' energy demands range between 0.5 and 2.0

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[24] See (Dincer & Cengel 2001).

[25] The water requirements to produce energy and the energy need to produce water, transport it and so on. (WWAP-UNESCO 2014).

[26] Wastewater treatment in this paper considers treatment and reuse mentioned by WWAP-UNESCO (2014) as single concept; due to the final destination previously mentioned and the high purification levels tertiary treatments already have.

kWh/$m^3$, while processes without nutrient removal have an energy demand lower than 0.5 kWh/$m^3$. On their side, Chae & Kang (2013) indicate in South Korea the whole WWT sector has an energy usage between 0.243 and 2.07 kWh per kg of biological oxygen demand removal. Both perspectives and numbers should be right because many factors[27] influence performance in WWTPs. In the USA the amount of energy demand compared to the whole electric sector is about 2 to 4% and in some communities WWTPs' demand can represent between 20 to 40% of their total consumption. This is very contrasting, for instance, with South Korea where the WWT sector accounts itself 0.5% of the national average (Chae & Kang 2013; Gude 2015).

The type of plant (technology) and arrangement have very influential effects over electricity consumption. It is well recognized that the major consumer technology amongst WWTPs is activated sludge; due to the extraordinary energy requirements to generate non-anoxic conditions through aeration processes (air pumping) (Rojas & Zhelev 2012; Chae & Kang 2013; Gude 2015). This process sometimes might consume about 50% of the total energy consumption of a plant (Rojas & Zhelev 2012; Chae & Kang 2013). In this sense, Gude (2015) and Plappally & Lienhard V (2012) made a benchmarking classification of the most representative plants in the USA, referencing B.E. Logan (2008), in which four types of WWTPs are presented with their respective ranges of energy consumption. However, types of treatment and energy requirements may change from case to case. To see how variable benchmarking can be, the next table shows different treatment techniques in Australia, China, USA and Japan (Plappally & Lienhard V 2012).

| Treatment Technique | Australia | China | USA | Japan |
|---|---|---|---|---|
| Lagoons | | 0.253 (avg) | 0.09–0.29 | |
| Activated sludge | 0.1 (avg) | 0.269 (avg) | 0.33–0.60 | 0.30–1.89 |
| Oxidation ditch | 0.5–1.0 | 0.302 | | 0.43–2.07 |
| Membrane bio-reactor | 0.10–0.82 | 0.33 (avg) | 0.8–0.9; 0.49–1.5 | |

**Table 4. Energy intensity (kW h/m3) of secondary wastewater treatment processes from different parts of the world,**

(Plappally & Lienhard V 2012)

Looking at the table above it could be seen, activated sludge and oxidation ditches are the most energy intensive techniques and both have in common that utilizes aeration processes to reach

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[27] Population, legislation of discharge, infrastructure, management amongst others are possible influential factors over electricity consumption in wastewater processes (Chae & Kang 2013; WWAP-UNESCO 2014; Gude 2015).

their depollution levels, which have been identified by other authors as highly energy intensive processes.

In a different way, Plappally & Lienhard V (2012) generated a benchmarking classification that considers energy consumption in WWTPs regarding the level of treatment, giving some general statistics by each step using examples around the world. *Primary treatments*, including pumping (ranging from 0.003 to 0.19 kWh/m$^3$) and primary sedimentation (0.008–0.01 kW h/m$^3$) with a 60% of Suspended Organic Solids (SOS) and 30% of BOD removed, have a total energy consumption between *0.01–0.37 kWh/m$^3$*. *Secondary treatments* have many technologies and methods of treatment. For example, recirculating in activated sludge consume an average of 0.011 kWh/m$^3$, mixing and pumping between 0.012–0.033 kWh/m$^3$, surface aerators have a consumption ranging from 0.41 to 0.83 kWh/Oxygen kg, efficient aeration devices consume about 0.026–0.04 kWh/m$^3$, fine diffusers consume 0.037 kWh/m$^3$ (avg), ultrafine porous diffusers 0.055 kWh/m$^3$ (avg), anaerobic digestion 0.5 kWh/m$^3$ (avg), aeration systems such as wetlands and land treatment use 0.13 kWh/m$^3$ and recirculation pumping in trickling filters consume 0.021 kWh/m$^3$ on average. In general, secondary WWT reported to be in the range of *0.16–0.45 kWh/m$^3$*. Tertiary treatment has very high values because the energy involved to finalize the treatment of wastewater varies from plant to plant: this, depends on the final grade of depollution and the standards of discharge to be fulfilled. Advanced water treatment with nitrification have a range of 0.40–0.50 kWh/m$^3$, anaerobic digestion working at 54–55 °C have a range of 0.09–0.29 kWh/m$^3$, dewatering with 0.3 kWh/m$^3$ (avg), reverse osmosis about 0.8–1.6 kWh/m$^3$, microfiltration system with polymer membranes 0.14 kWh/m$^3$ (avg) and ceramic membranes consuming 0.06 kWh/m$^3$. So, the whole energy consumption by a *tertiary level of treatment* may range between *0.23 and 10.55 kWh/m$^3$*. Such variations in treatment types and technologies could be appreciated more commonly in secondary and tertiary treatments[28], nevertheless applies to all wastewater treatment levels. Therefore, Rodriguez-Garcia et al. (2011) state that complexity of technology and energy consumption are directly related to the final destination standards; basically, because electricity and chemicals consumption rises with technology's complexity which is correlated with the pureness of discharge the site demands. To exemplify energy demand of different processes into a plant, Figure 6 and Figure 7 show treatments with their respective energy requirements in a common activated sludge treatment plant.

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[28] The literature identifies tertiary treatment as the most advanced in depollution, but also the most energy demanding ones (DOP 2013; Rodriguez-Garcia et al. 2011).

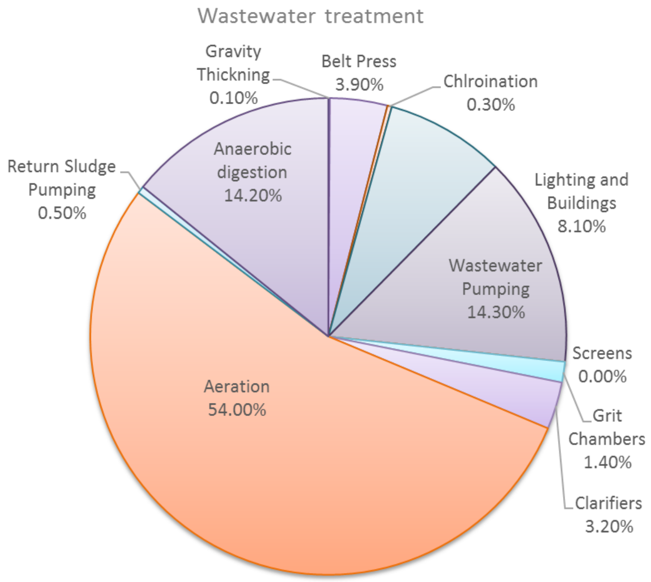

Figure 6. Distribution of energy requirements for conventional wastewater treatment operations and processes.

As an example how a wastewater treatment plant consumes energy, the next diagram shows the flow of matter over each step and process with their respective energy consumption; so to say, from raw wastewater pumping until the final water effluent and dried sludge disposal.

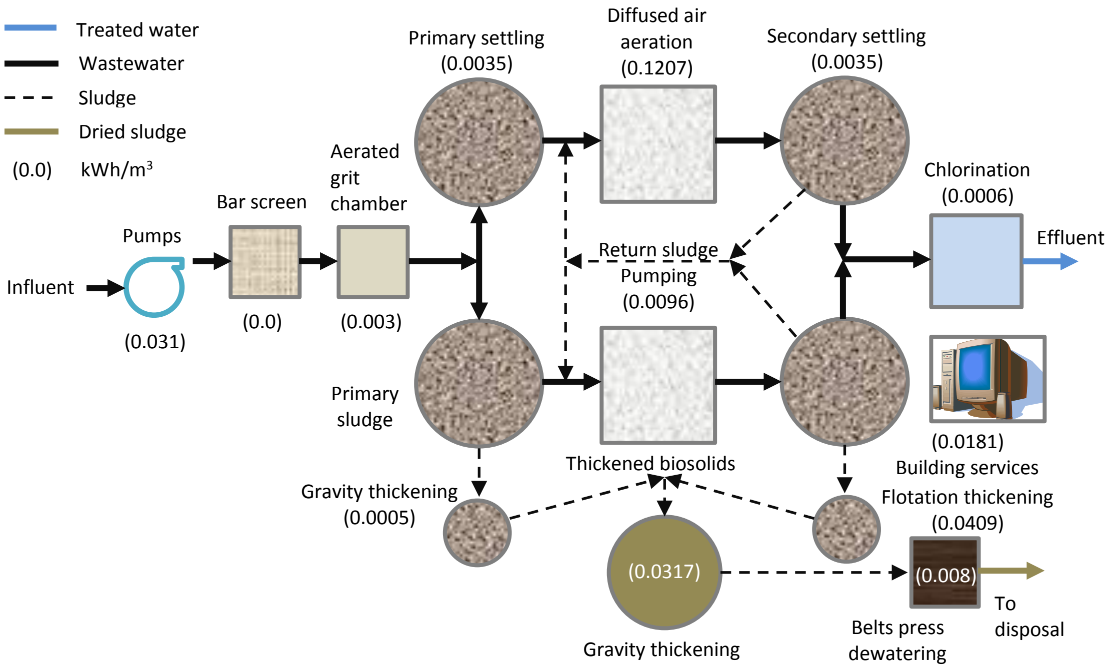

Figure 7. Representative Activated Sludge Wastewater Treatment Process Sequence (with Typical Daily Electricity Consumption for 44,048.98 m³/d Facility)

Despite the highly intensive energy requirements some technologies have, some authors mentioned energy demand (per $m^3$) in treatment plants generally drops and rises in relation with the scale of the plant and the economies of scale; the larger the plant the lower the electricity consumption is (Rodriguez-Garcia et al. 2011; Gude 2015). However, not only an accurate initial design has a role into the efficiency of energy use (kWh/$m^3$), also management and knowhow may achieve better results in treatment efficiency terms. As an example, Table 5 presents data[29] Rodriguez-Garcia et al. (2011) gathered for their analysis. All plants use aerobic processes to depollute, so, their energy consumption tends to be high due to aeration technology; in which, the most common treatment method is activated sludge, with some few exceptions using extended aeration and oxidation ditch. Additionally, two plants are integrated with tertiary treatments. Performance amongst WWTPs vary depending on the plant, but generally it could be said: plants 1,3 and 5 have over performances with respect their original designs, nevertheless their energy consumptions do not range amongst the highest values; especially, for plant 3 that has an exhaustive technology of treatment (high efficiency removal and energy consumption). Plants 2 and 6, with the most equilibrated performance tend to have moderate energy consumptions in comparison with the rest. This can be appreciated particularly in plant 6, which has the greatest removal efficiency, the best performance with respect to its original size and a tertiary treatment, which usually consumes a lot of energy. Contrasting with this, plants 4 and 7 have underperformance of 22 and 33% respectively and the highest values of energy consumption per $m^3$ treated. Such deficit is especially remarkable for plant 7 (the worst performer) because despite having the most basic method amongst the plants and produces a relevant amount of energy, its energy consumption ranges as the second high. Regarding the costs, it was not possible to compare the plants because prices in the report vary too much amongst them, hence, no direct relationship was found. The authors mention operators usually negotiate electricity prices independently, creating different realities to be compered and confirming management has an important role in operational costs. To have an idea and compare the cost of energy amid plants, a general price of energy was taken from Statista (2015) to be applied to all energy consumptions rates and generate results without variable prices; this, in order to evaluate performances of such plants in a context of fixed prices. It was found three things: one, negotiation of energy prices may

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[29] The table shows only 7 plants from the 24 analyzed by Rodriguez-Garcia et al. (2011) because the intention is to show how management and the original design may influence energy utilization in WWTPs. Another reason to select these 7 plants is the similarity they have respect to each other (technology and discharge standards) to be compared.

influence economic performance positively from 3 to 39% in lower prices and negatively, increasing prices from 25 to 60% in comparison with a fixed price; two, free electricity markets (non-regulated) allow plants' managers to compensate high energy loads and on the other side, might sink achievements as energy efficiency and self-generation; three, with fixed energy prices any energy achievement, in terms of energy efficiency or cogeneration, is reflected directly to the final price of treatment.

| | Design cap. **m3/d** | Real treatment. **m3/d** | Over or under cap. **%** | Treatment technology | Site of discharge | Removal efficiency **(COD)** | Energy consumption **kWh/m3** | Energy generation **kWh/m3** | Operation cost **(energy) €/m3** | Operation cost* **(energy) €/m3** |
|---|---|---|---|---|---|---|---|---|---|---|
| **WWTP 1** | 26,480.00 | 53,935.00 | **203.68%** | AS | AL | 83% | **0.13** | - | - | **0.0130** |
| **WWTP 2** | 54,560.00 | 51,111.00 | 93.68% | AS | AL | 89% | 0.14 | - | 0.013 | **0.0141** |
| **WWTP 3** | 24,640.00 | 45,227.00 | **183.55%** | OxD | AL & LndF | 93% | **0.2** | - | 0.027 | 0.0201 |
| **WWTP 4** | 8,080.00 | 6,300.00 | **77.97%** | EA+TT | AL | 96% | **0.54** | - | 0.039 | **0.0542** |
| **WWTP 5** | 12,000.00 | 14,722.00 | 122.68% | AS | AL | 93% | 0.29 | - | 0.028 | 0.0291 |
| **WWTP 6** | 40,000.00 | 38,634.00 | 96.59% | AS+TT | AL | 96% | 0.27 | 0.1 | 0.041 | 0.0271 |
| **WWTP 7** | 20,664.00 | 13,681.00 | **66.21%** | AS | AL | 94% | **0.33** | 0.24 | 0.084 | **0.0331** |

Note: Activated Sludge (AS), Oxidation Ditch (OxD), Extended Aeration (EA), Tertiary Treatment (TT), Agricultural Land (AL),Landfill (LndF) and Type 2 (T2); Operation cost* are calculated with a single common Spanish electricity price (10 € cents/kWh) from Statista (2015).

**Table 5. Performance and energy efficiencies of WWTPs in Spain.**

Energy prices are very influential, especially, where free electricity markets operate; this, due to them may well represent about 25 to 40% of the total operational cost. In this regard, Rodriguez-Garcia et al. (2011) mention plants share a common cost configuration during their lifespan that situates energy as one of the costliest factors during operation: energy, 26%; staff, 35%; and others with 39%. Coinciding with them, Rojas & Zhelev (2012) mentioned electricity, after labor, is the larger operation cost in WWTPs, accounting from 25 to 40% of the total costs. Also mentioned by them, it was registered that local governments in the USA might expend up to 33% of their budget in WWT and the energy needs of such process is estimated to increase by 30 to 40% in the next 20 to 30 years. To cope with these probable rises in energy and prices, energy recovering has been seen as an alternative by some (Gude 2015; Mo & Zhang 2013; Khiewwijit et al. 2015; Chae & Kang 2013; Chen & Chen 2013). Gude (2015) states that normally wastewater contains about 9.3 times more energy what is used to treat it and in some cases energy content may range between 3.6 and 13 times of the required value if organic and heat recovery are considered (see Figure 8). More detailed information about energy recovery and efficiency will be presented in the next sections of this chapter.

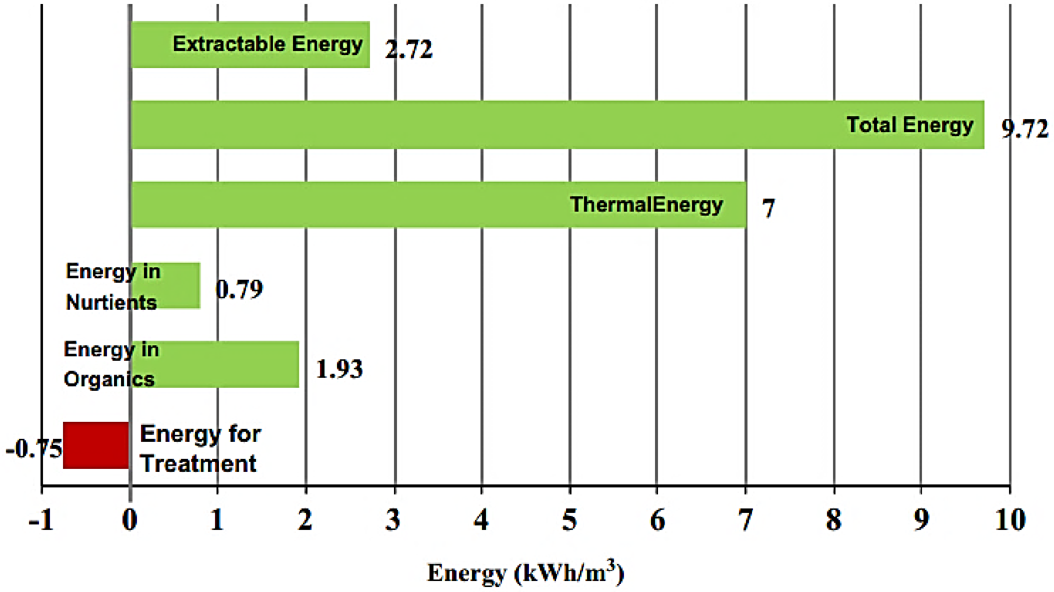

**Figure 8. Available energy forms in wastewater sources,** (Gude 2015)

## Energy in WWTP in Mexico

In Mexico, concepts as water pumping and sanitization account over 550 million euros yearly in electricity bills. This is considered as bad by CONAGUA and the commission recognizes a big portion of that money is wasted in old and low efficient equipment and underperformances (CONAGUA 2009). Despite some commission's reports mention energy as important issue there is lack of information about energy usage in the wastewater sector in Mexico. This has been recognized by SEMARNAT, pointing there is no specific data by plant to serve as basis (Ramírez & Vázquez 2012b). However, it has been found some data that may allow make an approximation. In Mexico City, an independent research group calculated the energetic consumption for wastewater treatment and resulted to be between 2.46 and 3.74 kWh/m$^3$. Additionally, the team predicted energy consumption in the sector will increase in the next decades (Centro Mario Molina 2011). In other report in the state of Veracruz, the CONUEE and the GIZ[30] analyzes the energy consumption of an integral water system (water production, treatment and management) in which energy demand is about 0.476 kWh per each m$^3$ to be treated.

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[30] CONUEE is the Efficient Energy Use National Commission and the German Corporation for International Cooperation, for its short name in German, GIZ.

With respect aerobic systems, an institute specialized in water in Mexico calculated the electricity (kWh) different aeration technologies may consume when remove BOD (mg/l) and generate treatment flow rate (l/s) (see Figure 9) (Mantilla et al. n.d.).

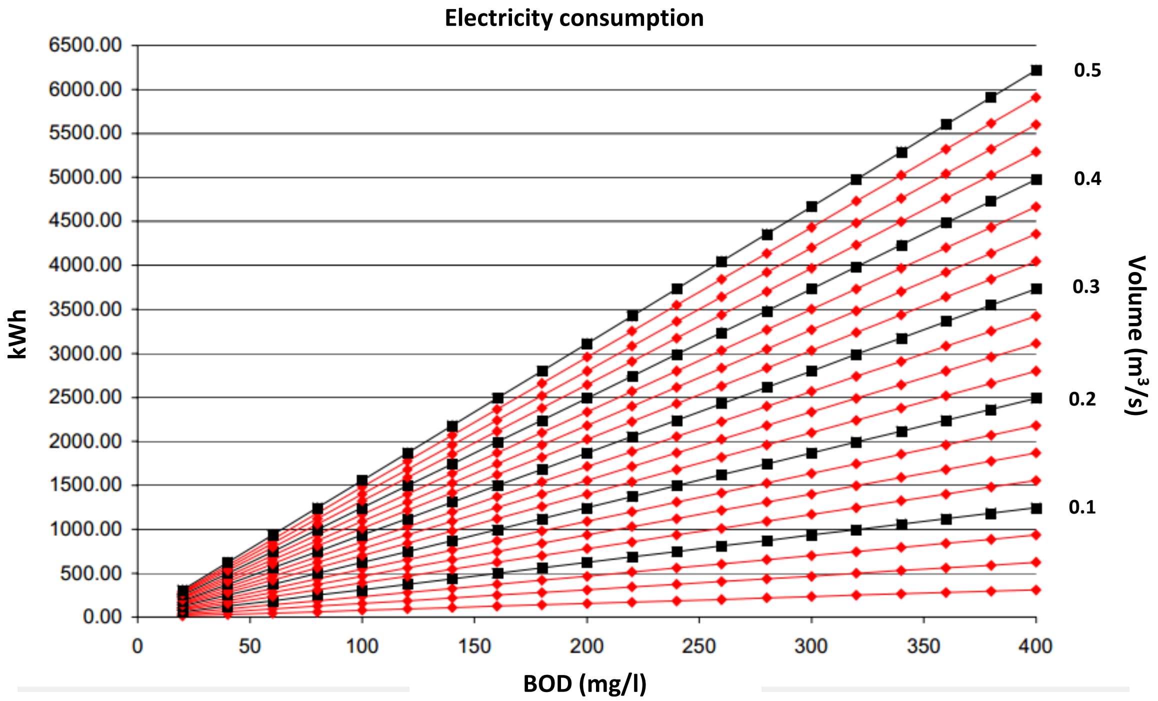

**Figure 9. Aeration technology energy consumption,** (Mantilla et al. n.d.).

As could be seen some case studies, energy use in wastewater treatment in Mexico varies significantly and considering this happens also in other countries; it can be said, variation is a common situation in WWTPs comparisons because depends on many factors, hence, no standard can be stablished. As an exercise, the present work, despite the lack of information, generates an estimation which will help to imagine the energy consumption and potential generation into the sector in Mexico. To do so, some official statistics, general numbers and assumptions are mixed to create an energy usage baseline of the sector.

Table 6 shows all technologies recognized as operative for municipal WWTPs in Mexico. For each technology it has been selected a representative energy intensity based on literature and, in some cases, adjusted; trying to simulate the situation in Mexico. It is important to highlight, energy intensity shown in the next 2 tables is not a *statistical work*, therefore *cannot represent* any *reality* of the sector. It should be taken as a simulation and nothing else. All energy intensities of aerobic technologies were selected with the premise to take the higher value found in case of a range, or the one with more likeness to the Mexican conditions. This, because efficiency in WWTPs in Mexico has been pointed by CONAGUA (2009) to be undermined by inexperience and very old equipment. For the case of anaerobic, more assumptions than specific data had to be done and such assumptions can be seen in Annex 1.

| Type | Technology | kWh/m3 | Source |
|---|---|---|---|
| **Aerobic** | Biological discs | 0.13 | (Williams, S n.d.) |
| | Biological filters | 0.42 | (Plappally & Lienhard V 2012) |
| | Oxidation ditch | 2.07 | (Plappally & Lienhard V 2012) |
| | Activated sludge | 1.89 | (Plappally & Lienhard V 2012) |
| | Aerated lagoons | 1.93 | (EDI 2011) |
| | Stabilization ponds | 0.29 | (Plappally & Lienhard V 2012) |
| **Anaerobic** | UASB | 1.81 | (Nolasco, D 2012) (Márquez et al. 2011) |
| | IMHOFF tank | 0.11 | (Nolasco, D 2012) |
| | Septic tank | 0.11 | (Nolasco, D 2012) |
| **Combined** | Enzymatic reactor | 0.14 | (Plappally & Lienhard V 2012) |
| | Dual | 2.31 | (PAHO n.d.) (Plappally & Lienhard V 2012) |
| | Wetland | 0.13 | (Plappally & Lienhard V 2012) |
| **Physicochemical** | Primary | 0.36 | (Plappally & Lienhard V 2012) |
| | Primary advanced | 0.37 | (Plappally & Lienhard V 2012) |
| **Tertiary and variations** | Others | 1.51 | (Plappally & Lienhard V 2012) |

Table 6. WWTP technologies operating in Mexico.

To generate Table 7 it was employed 2013 statistical data related to the treatment capacity of technologies (CONAGUA 2014c), which was merged the calculated energy factors of Table 6.

| System of treatment (Technology) | No. Of plants | Treated flow m3/s | Thousand of m3/yr | Treatment GWh/yr |
|---|---|---|---|---|
| Biological discs | 13.00 | 0.60 | 18,985.57 | 2.45 |
| Biological filters | 38.00 | 1.76 | 55,496.28 | 23.31 |
| Oxidation ditch | 17.00 | 0.79 | 24,827.28 | 51.39 |
| ***Activated sludge*** | 699.00 | 32.37 | ***1,020,839.53*** | **1,929.39** |
| Aerated lagoons | 33.00 | 1.53 | 48,194.14 | 92.77 |
| ***Stabilization ponds*** | 722.00 | 33.43 | ***1,054,429.38*** | **305.78** |
| ***UASB*** | 193.00 | 8.94 | ***281,862.70*** | **508.96** |
| IMHOFF tank | 52.00 | 2.41 | 75,942.28 | 8.61 |
| Septic tank | 95.00 | 4.40 | 138,740.71 | 15.73 |
| Enzymatic reactor | 60.00 | 2.78 | 87,625.71 | 12.27 |
| Dual | 16.00 | 0.74 | 23,366.86 | 53.98 |
| Wetland | 70.00 | 3.24 | 102,230.00 | 13.29 |
| Primary | 21.00 | 0.97 | 30,669.00 | 11.04 |
| Primary advanced | 11.00 | 0.51 | 16,064.71 | 5.94 |
| ***Others*** | 247.00 | 11.44 | ***360,725.84*** | **543.89** |
| **Total** | **2,287.00** | **105.90** | **3,340,000.00** | **3,578.81** |

Table 7. Wastewater treatment capacity and energy use.

As can be observed in the simulation numbers, activated sludge would have the biggest share into the total demand with 54%, despite to be the second largest in number of plants and effluent treated. Stabilization ponds which treat 31.5% of the total effluent and is the largest technology in Mexico with 772 plants, would use 8.5% of the total energy. The third most applied technology, UASB, in comparison with the second largest consumes 6 times more energy and treats 70% less volume. The other big number is made by "others" in which it is assumed many technologies are involved, nonetheless, would be interesting to know what technologies are referred as others by CONAGUA and then research possible energy intensities for them. The total energy intensity of the sector into the country would be 3.578 TWh, which represents 1.38% compared with the total electricity generated in 2013 (258 TWh). This does not appear so disproportionate since the country just treat 46% of generated wastewater and faces big problems with efficiencies in its plants. In comparison to other countries as USA (2 to 4%) and Korea (0.5%) the fraction with respect total generation seems to be near to the reality realm, however, more accurate data about population, efficiencies and other factors might be taken into account to improve this kind of simulations. Considering the data presented before, it could be said Mexico has an *average efficiency of treatment of 1.07 kWh/$m^3$* what would be above the range Figure 5 shows.

### *Factors that represent a major energy consumption*

As mentioned before, equipment and their arrangement influence heavily energy consumption in plants and these initial design factors may represent an increase of electricity consumption during the lifespan of the plants if they are not well selected. A basic one is the right selection of the motors (pumps), which has to be selected considering environmental and maneuver conditions to operate as near as possible to the nominal capacity. Working near to the design conditions has several advantages and one of them is rewarded by CFE. The Power Factor[31] (PF) has a minimum advisable in working circumstances for CFE (90%) and any lower digit represent wasted energy, therefore, is penalized by the electricity company with an extra charge. On the contrary, any value above 90% is rewarded by the retail company. Motors may generate a low PF if they are running under 50% of the nominal load. This, in consequence, may generate negative effects over the system such as voltage drops, overloads, heating effects on transmission lines, energy losses and damages. When this is repaired and brought back to efficient levels the system's voltage is helped to be stabilized, losses in cables and operating equipment are diminished, equipment and infrastructure lifespan is increased, as well as the economic benefits (fines and rewards) mentioned before. Thus, equipment as pumps may work as near as possible to the maximum capacity conditions (between 3/4 and 4/4 of their capacity) and non-stop equipment should not have frequent starts and stops. This, in addition to the right size of cables selection (avoiding the Joule effect) might reduce potential energy losses (CONAGUA 2009).

### *Equipment and methods to reduce energy consumption*

There also exist methods and equipment helping to reduce energy consumption in plants: demand controllers, starters, efficient motors, capacitor banks, filters, intelligent and efficient lighting and so on. Firstly, to better manage energy consumption it is necessary to know the peak demand of the system and then evaluate the chances to distribute demand and reduce peaks in order to generate an ideal demand; which is a very cheap way to get lower energy costs. To administrate the maximum demand and become it into an ideal, it is necessary identify whether the loads are transcendental or not; meaning, each of them should be analyze in terms of transcendence, daily variation and level of importance, as well as, the power of the load. Finally, after having the analysis mentioned above, the demand control (manual or automatic) should be selected,

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[31] The power factor is the factor that express the right (efficient) use of electricity towards mechanical work; being expressed in % and coming from the next formula *PF= kW/kVA* (CONAGUA 2009).

considering the means that the plant counts. This may help to reduce costs of operation due to a lower peak demand represent lower tariffs. Another but more invasive and costly options are motor starters and efficient motors[32], which have direct effects (cutbacks) over demand. However, efficient motors are expensive and therefore an investment analysis must be carried on before any expense. A less costly and more popular option is efficient lighting, which has nowadays amazing results in comparison with conventional and old fashioned lamps. The current commercial technology may achieve improvements in energy usage between 35 to 60% less than conventional. The already mentioned options can help operators to reduce energy consumption in different ways and levels, nevertheless, technologies as renewables also may help to coupe with high energy consumption while generating energy and reducing dependency of plants (please, see last sections of this chapter).

### *Electricity tariffs in WWTPs in Mexico*

In Mexico, the electricity sector works with different tariffs to offer service to all kind of clients, depending on their power demand, kind of service and load. The price of each tariff is agreed once in a year considering agreements and the inflation and is suitable of changes (majorly rises) when the situation change the original assumptions. In this regard, the water sector counts with a special tariff that allow municipalities and operators to achieve lower operation costs for the sake of the public; being not the case for private operators who have to pay general tariffs compulsory.

Table 8 shows all applicable non-fixed tariffs for the water sector in Mexico, being just tariff 6 the one with a special price for public services. Tariffs 2 and 3 are into the low voltage package offered to all commercial and industrial clients. These three tariffs (2, 3 and 6) are commonly used by operators in small towns or low flow conditions (CONAGUA 2009). Despite tariff 6 has no limit or average regarding voltage levels, the majority of municipal operators and public plants do not uses such tariff for unknown reasons: report CONNUEE/GIZ (2011). For intermediate users, tariffs O-M and H-M offer in medium voltage two different scales, just requiring some small equipment. Major users are forced to count with a substation to be connected and access tariffs H-S and H-SL, which have some restrictions in terms of usage. All tariffs are subjectable to strategic zone prices, therefore, users have to take into account what prices are valid into their respective locations (CONAGUA 2009).

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[32] Efficient motors may represent 25% of energy savings in comparison with non-efficient ones (CONAGUA 2009).

| Tariff | Description | Type | Apply to |
|---|---|---|---|
| 2 | GS until 25 kW | General | LV until 25 kW of demand |
| 3 | GS from 25 kW | General | LV from 25 kW of demand |
| 6* | Water and wastewater pumping | Especific | Public service: pumping |
| O-M | Ordinary MV | General | MV-GS; demand until 100kW |
| H-M | Scheduled MV | General | Schedule MV; demand from 100kW |
| H-S | Scheduled HV Subtransmission | General | Schedule HV; subtransmission from 35 to 220 kV |
| H-SL | Scheduled HV Subtransmission | General | Schedule HV; subtransmission until 220 kV |
| Note: General Service (GS); Low Voltage (LV); Medium Voltage (MV); High Voltage (HV); (*) Preferential tariff. | | | |

**Table 8. Water service tariffs in Mexico,** (CONAGUA 2009)

## *Residual energy in wastewater treatment in Mexico*

Energy contained in wastewater organics is about 2.6 times bigger with respect the energy employed for treatment and the methane ($CH_4$) that could be extracted from anaerobic digestion may cover between 25 to 50% of WWTPs' energy requirements, mentions Gude (2015). In Mexico, the amount $CH_4$ potential per technology and their respective generation in municipal wastewater have been calculated by Ramírez & Vázquez (2012a); this, with the intention to depict the sector's GHG emission potential. Results in Table 9 show the *major polluter* and *$CH_4$ emitter* is *untreated wastewater*[33] with 68.47% of emissions; the second larger emitter technology is activated sludge; technologies as *biological filters*, *dual*, *aerated lagoons* and *stabilization ponds* range between 300 and 400 Gg of $CO_2$ eq; and finally, technologies with the higher emission factors (IMHOFF and UASB) pollute less than other technologies with lower emission factors. Following the objectives of this works, the already mentioned data can be transformed into *energy content potential*; transforming the mass (metric tons) produced in one year into volume ($m^3$) with an energy content of 13.89 kWh/$m^3$ and then transformed into *GWh/yr of thermal and electrical energy*[34].

In this regard, Table 9 shows the amount of $CH_4$ generated in one year by wastewater in Mexico has the potential to cover near 67% of the total energy employed for treatment in the country (3,578.8 GWh/yr). However, this amount of energy is not fully recoverable because exist physical limits and structural reasons. For example, number 7 has the major energy content, but such content –that accounts 68.47% of the total methane generation– cannot be recovered because

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[33] Constant untreated wastewater discharges generate anoxic conditions in water bodies, which in turns create an excessive $CH_4$ generation (Ramírez & Vázquez 2012a).

[34] Electric conversion of biogas is given by Gude (2015)

anaerobic reactions take place in open spaces such as rivers and lakes, making impossible its capture. Additionally, technologies as stabilization ponds and wetlands cannot be considered due to the similar capture conditions mentioned above. This situation just left the rest of technologies, accounting by themselves 2,066.38 and 681.91 GWh/yr of thermal and electric power, respectively. In this sense, it could be said a major catchment and treatment of wastewater in Mexico might have a double benefit: one, reducing sector's emissions and two, increasing energy recovery potential; which could be also increased, if novels anaerobic technologies are applied to cover the 68.5% of (non-treated) wastewater in Mexico.

| No. | System of treatment (Technology) | Emission facttor in CH4 (kg)/BOD (kg) | Emissions with respect its use (Gg of CO2 eq.) | Emissions in CH4 (Ton)/yr | CH4 (m3)/yr | % | Energy content considering LHV (GWh) | Electricity in GWh (33% efficiency conversion) |
|---|---|---|---|---|---|---|---|---|
| 1 | IMHOFF tank | 0.6 | 35.60 | 1,424.00 | 3,390.48 | 0.27% | 19.78 | 6.53 |
| 2 | UASB | 0.6 | 128.52 | 5,140.80 | 12,240.00 | 0.98% | 71.42 | 23.57 |
| 3 | Biological filters | 0.36 | 381.56 | 15,262.40 | 36,339.05 | 2.92% | 212.04 | 69.97 |
| 4 | Dual | 0.36 | 308.51 | 12,340.40 | 29,381.90 | 2.36% | 171.45 | 56.58 |
| 5 | Enzymatic reactor | 0.36 | **6.56** | **263.60** | **627.62** | **0.05%** | 3.66 | 1.21 |
| 6 | Others | 0.36 | 80.08 | 3,203.20 | 7,626.67 | 0.61% | 44.50 | 14.69 |
| 7 | Water bodies discharge (non-treatment) | 0.36 | **8,959.68** | **358,387.20** | **853,302.86** | **68.47%** | **4,979.14** | **1,643.12** |
| 8 | Wetland | 0.36 | 34.01 | 1,360.40 | 3,239.05 | 0.26% | 18.90 | 6.24 |
| 9 | Septic tank | 0.3 | **6.01** | **240.40** | **572.38** | **0.05%** | 3.34 | 1.10 |
| 10 | Activated sludge | 0.24 | **1,991.79** | **79,671.60** | **189,694.29** | **15.22%** | 1,106.89 | 365.27 |
| 11 | Aerated lagoons | 0.24 | 304.74 | 12,189.60 | 29,022.86 | 2.33% | 169.35 | 55.89 |
| 12 | Biological discs | 0.24 | 14.48 | 579.20 | 1,379.05 | 0.11% | 8.05 | 2.66 |
| 13 | Oxidation ditch | 0.24 | 96.92 | 3,876.80 | 9,230.48 | 0.74% | 53.86 | 17.77 |
| 14 | Primary | 0.24 | 81.23 | 3,249.20 | 7,736.19 | 0.62% | 45.14 | 14.90 |
| 15 | Primary advanced | 0.24 | 282.30 | 11,292.00 | 26,885.71 | 2.16% | 156.88 | 51.77 |
| 16 | Stabilization ponds | 0.18 | 373.75 | 14,950.00 | 35,595.24 | 2.86% | 207.70 | 68.54 |
|  | **Mexico** | **0.33** | **13,085.74** | **523,430.80** | **1,246,263.81** | **100%** | **7,272.13** | **2,399.80** |

**Table 9. Technologies $CH_4$ emission factor in Mexico,** (Ramírez & Vázquez 2012a).

## Renewable energies and their role in WWTPs

Due to the recent expansion and boom of some renewable energy (RE) technologies around the world, especially for solar and wind, the investment for all renewable technologies has increased amongst developed and developing economies. New RE technologies shared about 8.2% of the global final energy consumption in 2010 and nearly half of the global electric capacity added for the period of 2011. This trend is influencing *all sectors* globally and is driven mainly by national policies. During this time, industries and governments have foreseen several challenges after the financial crisis of 2009; even so, new RE markets and business trends have emerged in developed economies. Despite the current leadership of North America and Europe, renewables market grows rapidly in developing economies all around the globe, mostly caused by strong commitments and policies[35] towards renewable energy implementation. Developing countries are using such initiatives not also for the same reasons developed economies started; in addition, they use renewables to attend historically faced problems as: job creation, equality, energy access, poverty reduction as well as others[36]. Thus, support and creation of this kind of strategies amongst developing economies seems to be benefiting in spite of global recession, forcing governments to bear the load and then ask research centers and private companies to be involved with (REN21 2012). One example of this effort is described by Devi et al. (2007) in which the mixed use of renewable and conventional energy sources is assessed in order to meet wastewater treatment energy requirements in rural India. As in other papers (Mo & Zhang 2013; Chae & Kang 2013; Nowak et al. 2015; Gude 2015), Devi et al. mention WWTPs have an intensive energy requirement as well as high costs, therefore, the intention to reduce such gap using low cost renewables for some parts of rural India. Energy balance optimization in municipal WWTPs in Austria is addressed by Nowak et al. (2015), claiming WWTPs ca become *energy positive* and *sustainable* by using Combined Heat and Power (CHP) systems using methane and heat pumps. In the same direction, another study explores the possibility to achieve energy independence incorporating sustainable energy resources, with the intention to reduce carbon emission footprints and find the way to accomplish regulation[37].

Mo & Zhang (2013) mention wastewater sustainability have two major approaches to be improved: energy efficiency[38] and resource recovery. The latter, constituted by nutrient recycling, water reuse and onsite energy generation (the main focus of this work), is widely discussed by the authors and they concluded integrated resource recovery is quite uncommon in practice. However, onsite and offsite energy recovery is a practice on rise, at least in research. In Mexico, renewable energies are briefly mentioned by some documents and institutions related with

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[35] The recent adoption of "Feed-in-Tariffs", renewable portfolio standards, rural electrification and small scale ownership programmes has increased rapidly the share of renewables in developing economies (REN21 2012).

[36] "Energy security, reduced import dependency, reduction of greenhouse gas (GHG) emissions, prevention of biodiversity loss, improved health, job creation, rural development, and energy Access" (REN21 2012).

[37] The Korean MOE aims to achieve 50% of energy independency in WWTPs by 2030 (Chae & Kang 2013).

[38] As seen before, energy efficiency improvement can be made by audits, internal controls and equipment replacement (CONAGUA 2009; Mo & Zhang 2013).

wastewater treatment, but seems their implementation is still under discussion (CONAGUA 2009; Ramírez & Vázquez 2012a; STPS 2013; Calderón Mólgora 2015; Limón Macías 2013). In this regard, Calderón Mólgora (2015) mentions, in Mexico, about 60% of energy demand for WWT could be covered by the energy contained into wastewater and renewable energy implementation is quite achievable in many cases.

### *Renewable energies review in WWTP*

Some authors has mentioned renewable energies are good choices for WWTPs to attain their energy requirements and to rise their independency from the electricity network (Chen & Chen 2013; Venkatesh & Elmi 2013; Wu et al. 2015; Björklund et al. 2001; Chae & Kang 2013; Han et al. 2013; Abusoglu et al. 2012; Power et al. 2014; Papong et al. 2014; Gude 2015). Technologies and applications differ amongst authors and case studies, but in general, the most applicable technologies to WWTPs can be summarized in: hydropower, heat-pumps, biogas and the universal sources (solar and wind). Next sections address more in detail each of these technologies and their relationship with wastewater treatment.

#### Heat recovery (heat pumps)

Heat pumps (HPs) is a very efficient way to collect heat from different sources (might be solar, geothermal, waste and exhaust heat) and apply it into heating or cooling processes with a minimum energy requirement (Deng & Gu 2012; Mo & Zhang 2013). In the U.S. the DOE made an estimation that 235 bill kWh of thermal energy, contained in wastewater, is discharged into sewage systems each year and such energy is ten times bigger the amount required to treat that water into already installed WWTPs in the country (Gude 2015). In this regard, Deng & Gu (2012) mention the great potential wastewater heat represents and the effectiveness of heat pumps to transfer it for reuse. In this study the authors made a model considering a residential area in China and its untreated effluent as a heating source for cooling and heating purposes using HPs. The stability of wastewater is highlighted by the authors as a benefit; this, because the non-intermittency in terms of temperature and supply such water has. As a result, the paper shows HPs systems attached to sewerage systems in China may offset fossil fuels needs for cooling and heating in the same generating area; becoming sewerage systems more sustainable. Hepbasli et al. (2014) in their review assess wastewater source heat pumps (WWSHPs) systems already existing in 33 locations around the world in terms of energetic, exergetic, environmental and economic aspects; resulting in a coefficient of performance (COP) for each of them. Results show in any city, about 40% of generated heat is going into sewage systems, wastewater temperature is constant along the year and commonly the difference between the ambient and wastewater is about 20°C, wastewater flow rate persists along the year and represent 85% of the total water consumption of a person. Additionally, WWSHP systems are a proven technology and environment-friendly, unfortunately, supply targets cannot be so far from the source because heat can be lost in in long distances.

### Biogas systems

Biochemical energy recovery it has been employed since many years ago in WWT processes. Biogas generated from anaerobic digestion (35 $m^3$/day/person approx.) has the potential (6.2 kWh/$m^3$ of WW) to supply energy generation systems, as Combined Heat and Power ones (CHPs), with a very stable gas. To do so, impurities have to be removed and the quality of the gas has to upgraded until reach similar characteristics of natural gas. Methane, the bigger component of biogas has a heating value of 100 BTUs/$m^3$ that con be converted into 2.24 kWh/$m^3$ of electric power if 33% of efficiency is considered (Mo & Zhang 2013; Gude 2015). In China a study developed by Chen & Chen, in 2013, evaluates energy production and emissions mitigation through biogas-sludge alternatives. As a part of the study, the substitution of other energy sources (coal and electricity) by biogas was assessed, concluding well applied biogas technologies (CHP and HBU[39]) may reduce WWTPs installation and operation costs. In the USA, Mccarty et al. (2011) compare $CH_4$ generation from conventional aerobic plants with sludge anaerobic digestion with full anaerobic treatment plants. Results show anaerobic treatment may become a net energy exporter by doubling the amount of energy required and aerobic treatment plants may nearly cover their energy requirements (83%) by producing biogas in sludge digestion.

### Hydropower

The use of turbines and other devices in ducts and streams is quite ancient in comparison with their implementation in WWTPs (late 70s and early 80s). However, the main generation factors (head, flow and efficiency of turbines) are the same in almost all applications (Mo & Zhang 2013). Power et al. (2014) analyze technical and economic aspects of 100 WWTPs between UK and Ireland, in which hydropower energy recovery is assessed through a sensitivity analysis; considering flow, turbine selection, electricity pricing, financial incentives and payback period. The authors found, economically viable hydro scheme installations in WWTPs are those with high flow

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[39] Household Biogas Use (HBU) (Chen & Chen 2013).

rates and with good governmental incentives. Also found, the best energy recovery point into such type of plants is the out flow and plants with less than 1kW and 1m$^3$/s cannot be considered for hydro energy recovery in all senses. To be considered economically viable, plants should have more than 3 kW of power potential and the related payback periods of the schemes ought to be smaller than 10 years. Between four selected turbines (Kaplan, Francis, Propeller and PAT), Kaplan had the best efficiency and also the greatest price. In contrast, pump as turbine (PAT) achieved a decent generation with a very low price. The authors say, in WWTPs the flow is more important than the head because such plants normally have no tall installations. In South Korea a couple of researchers evaluated a WWTP energy independence with the implementation of some renewable energy technologies. Amongst them a Small Hydropower SHP scheme was assessed. They found SHP systems implemented over WWTPs cannot contribute so much towards energy independence (1% in total) and also such systems ranked as the most expensive technology in the study (Chae & Kang 2013).

### Solar and wind

Wind and solar technologies applied to WWTPs are being mentioned, reviewed and studied by some authors (Mo & Zhang 2013; Chae & Kang 2013; Han et al. 2013; Wu et al. 2015; Plappally & Lienhard V 2012). Mo & Zhang (2013) mention the space demanding factor of such technologies suits very well with large spaces WWTPs commonly have, but the enormous capital investment they need can be a barrier for implementation over such type of plants. Solar and wind are considered relatively universal, and therefore, to be applicable anywhere (Chae & Kang 2013; REN21 2012). As an example, Han et al. (2013) reported a decentralized integrated PV and oxidation ditch standalone system (without battery storage), that runs over the day with aerobic processes and stops during night, giving pace to anaerobic ones. The authors reported solar energy is suitable for WWT in remote areas due to the dispersion of treatment systems and the high energy requirements some technologies have.

## Conclusion

Regions in Mexico have totally different situations related to water stress and the municipality of San Luis Potosi is one with the most severe ones. Despite the city treats about 74% of its effluent and carries big amounts of water from a near state, the future water supply is foreseen to be scarce. Additionally to water stress, some places in the state faces difficulties to treat wastewater due to the lack of money. In the country no-payment accounts 30% of collection deficit and mal pricing into the sector generates many financial problems. Maybe this explains why in Mexico only

46% of domestic wastewater and 28% of industrial is treated, while 92% of the total is collected. In terms of energy, it was found aerobic treatments are the most demanding ones and their operational costs are highly influenced by electricity prices; however, such costs are suitable of improvement applying good management and negotiation skills, as well as renewable energy implementation. WWTPs energy consumption in Mexico, regarding types of plants and locations, vary as much as other countries, but a scenario made in this work shows activated sludge, UASB and stabilization ponds are the most demanding ones. The same scenario also shows Mexico might be using 1.38% of the total energy employed in one year, which is very high if the low treatment rate in the country is considered. In general, the scenario shows average treatment in Mexico (1.07 kWh/$m^3$) might be above the range (0.62 – 0.87 kWh/$m^3$) UNESCO reports for the world. On the other hand, the sector might count with enough capacity to generate about 19% of electric energy employed for treatment today (681.91 GWh against 3,578.8 GWh/yr) and if non-treated but collected waste water is included and treated with novel anaerobic treatments it might be possible to produce about 65% of all energy employed for treatment, as well as reducing 97% of sector's $CO_2$ eq. emissions. The literature review shows energy independence is achievable in some cases, however, independence or net energy production cannot be achieved without considerable high economic investments, which can undermine implementation. Therefore, any project should be analyzed and evaluated with proper methodologies, considering policies, technical and economic factors.

# Energy and Wastewater treatment policies – Chapter 2

## Introduction

Mexico has been characterized for having a closed energy market policy, in which state owned companies (PEMEX and CFE[40]) used to have complete control over all energy issues. During the last two decades, some changes have allowed private investment in some areas, but the main activities remained held by the state. This has changed since the Mexican government, in 2013, renovated the rules and opened the energy market for private investment (DOF 2014a). Previously to that and as a part of Mexico's treaties, the Mexican government committed itself to generate policies to align its performance to the global warming and climate change alleviation. And as a result of both, the government has set a group of tools and national strategies in which intend to reduce $CO_2$ emissions, boost RE usage, generate stability and at the same time decrease the enormous poverty gap and lack of services part of the population suffer to date (SENER 2009; SENER 2011; SENER 2012).

Related to energy, the role of fossil fuels into the country is enormous and is planned to be maintained in the near future, mainly for some oil and gas technologies that have been declared clean. This historical tendency continues despite the national commitment to achieve 50% of clean energy sources amongst electricity capacity by 2050. It is also foreseen that energy efficiency may play a role, reducing energy demand and GHG emissions by this period. Today the share of non-fossil sources into the electricity generation mix is about 15%, comprised mainly by big hydro and to a lesser extent by nuclear, geothermal, wind and biomass. The development of solar energy has remained untapped despite México's solar potential[41] (SENER & GIZ 2012; SENER 2012; CRE n.d.).

As another strategic element of development, water has been recognized by the government as a hinging point of all strategies and processes in Mexico. Strategies in Mexico to date try to cope with the increasing demand and scarcity, as well as the danger climate change represent to the resource access. Additionally, pollution of water bodies is increasing in Mexico due to the growing generation of wastewater and its deficiency of treatment, which has derived in several environmental and social problems in the last years. During 2001 and 2006, wastewater treatment into the country grew from 23 to 36% of the total generation through a massive effort that was considered as a success in governmental terms and set the basis of the ongoing policies. However,

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[40] PEMEX is the petroleum Mexican company and CFE is the Federal commission of electricity.

[41] The potential of sun power in Mexico is esteemed at 5.5kWh/m2/d average (SENER and GTZ, 2009).

in the following period (2007 to 2012), the government's commitment towards the Millennium Development Goals (MDG) rose the objective until 60% of treatment; considered too high for the reality of the sector. As a proof it, the objective has not been accomplished even today; being treated in average 46% of the total wastewater generation. However, the federal government has continued supporting and financing tools and programmes to increase treatment amongst municipalities, water operators and the industry; this, with the hope such stakeholders materialize implementation (De la Peña et al. 2013).

## Policies and their impact review

Countries' goals is commonly pursued by policies since ancient times, so it can be said they are common governmental practices towards particular objectives (Lundvall & Borrás 2013). For example, India, a country with a high fossil fuels dependency (68%), is intending to integrate more renewable energy as part of its energy mix by 2022. The integration of such sources into the energy mix faces some challenges, especially those related to economics. In this regard, federal and state policies applied to boost renewables were analyzed by Shrimali et al. (2016) in order to determine the most cost effective ones. The authors found, the combination of federal and state support policies is more cost effective than separated. Also, policies addressing main barriers (specific or general) were found to be more effective deploying RE rather than general implementation policies.

On a different side and situation, RE policies in Germany face big interests lobbing while balance should be kept in a highly competitive environment (Strunz et al. 2015; Deppermann et al. 2016). The case of biofuel policies in Germany pointed by Deppermann et al. (2016) shows European biofuel policies support a technology generation that has been persistently questioned by scientists and organizations, and also explains how the reason to maintain such policies as valid might be the combination of European RE targets and big economic interests. The common belief is biofuels increase agricultural sector income and without supporting policies massive negatives effects will come to farmers. The authors found in their models, in deed, negative effects are foreseeable for the sector if an abolishment gets in, but contrary to many biofuels supporters claim, they found effects would be smaller and not generalized. Therefore, the authors conclude income diminishing reasons are not enough to justify the stand of current policies and apparently are powerful agricultural sector interests that maintain them. Regarding lobbing and interest pressure over RE policies, Strunz et al. (2015) found in competitive environments, such as the

European union, RE policies are often affected by many stakeholders[42] interests and roles, especially by the most influential ones (corporations). The paper suggests RE policies implementation in Germany succeed because many interest have been accomplished by now, however, robust and anti-lobbing policies for long run cannot be accomplished until a pure economic rational reaches the ruling strategies.

Continuing with challenges and roles in policy implementation, Barbosa et al. (2016) bring the case of water policy implementation in Sao Paulo (Brazil), introducing the "policy implementation gap"; a concept that describes the variety of factors that can stem successful policy implementation. Amongst them, imprecise definitions and roles as well as ineffective stakeholder's participation are some of the most typical factors creating the gap. In such analysis, the authors found institutional and governance issues (political will, communication amongst agencies and technical capabilities) are the most challenging issues towards policies and projects implementation than financial and technical difficulties. This reveal the inexperience and lack of knowledge amongst policy makers, bureaucrats and other stakeholders are the propellers to increase the implementation gap, especially in chaotic and emerging places where the interests are normally deviated from policies' goals.

Looking how knowledge and stakeholders interaction signify to the implementation of policies in the already presented cases, it is interesting to see what Lundvall & Borrás (2013) argue for the case of the OECD countries and the leverage effect knowledge and technology policies have over national objectives. The authors mentioned three stages in which policies help knowledge generation and application; based on the manner they interact and influence other parts of a society (corporations, universities, productive sectors and so on). Science, technology and innovation policies are the different policy stages that push knowledge involvement into the development of a country. The first stage (science policy) set the understanding basis and the rules of the game; in other words, the ruling platform. For example, it is necessary to create physics and engineering schools before to even think the installation of a nuclear reactor. The second stage, technology policy, is a focused policy applied over specific technologies and sectors and requires a major participation from the industry and markets. The third stage (innovation policy), is when the

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[42] Companies, bureaucrats, politicians and voters are the most common interest that drive RE policies in Europe (Strunz et al. 2015).

government abandons the leadership and consent markets and competitiveness to become the pushers of knowledge.

These stages are more less palpable in the environmental protection policies implementation Schmidt & Huenteler (2016) describe for developing countries discussed below.

Despite the highly debated green growth and other concepts of sustainable development, the adaptation and absorption of environmental policies and technologies amongst developing countries have increased. Its attraction relies on the fact policy makers see in this upcoming agenda and business model an opportunity to create jobs, increase competitiveness and protect the environment. Different technologies have been adopted by developing economies, being mostly mature clean technologies[43] embraced. The hope some countries have in deploying such technologies is to start markets that eventually become manufacturing nucleus for international competition (Schmidt & Huenteler 2016). Green technologies deployment process in a catching-up country has many similarities and connections with the three stages mentioned before. For example, the first step of catching-up green technologies depends undeniably on prior science policies implementation because technology transfer causes many knowledge and machinery imports that have to be absorbed by an existent scientific base, otherwise such transfer cannot be possible. So, for green technologies transfer it is advisable to firstly implement related *scientific policies* (knowledge and human resources generation) before *technology policies* (technology deployment and manufacturing). To localize manufacturing industries or develop new sectors (second step), associated knowledge has to exceed basic science and depending on the maturity of the technology, capabilities must be more or less developed[44]; not only in education institutions also in industry and commerce. So, it could be said, technology policies implementation has to be accompanied with an industry and local economy capable to adapt to new technologies and markets in order to succeed. Once a sector or an industry promoted by policies are well stablished, the competitiveness into local markets and/or abroad depends on innovation (third step), which in this case has two ways of being. One, *design capabilities* that attend technologies based on *product innovation* and two, *manufacturing skills* that increase competitiveness trough *efficiency in production*. (Lundvall & Borrás 2013; Schmidt & Huenteler 2016).

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[43] The authors consider clean technologies: hydro, wind, solar, water sanitation and efficient process (Schmidt & Huenteler 2016).

[44] Research and development (R&D) capabilities are more with new technologies and production capabilities with the most mature ones (Schmidt & Huenteler 2016).

Contrasting Lundvall & Borrás (2013) stages with the technological catching-up process described by Schmidt & Huenteler (2016), it was observed both are good parameters to compare and identify policy implementation and technology catching-up processes in developing economies. Considering this and the fact Mexico is a developing economy that intends to implement and increase green technologies usage, the present work considers both authors' perspectives as useful tools for methodology of assessment over the ongoing energy policies in Mexico. To do so, the following sections will present the current energy policy structure, with the intention to identify main barriers and advantages towards successful policy implementation and thereafter an assessment of such policy group will developed with the mentioned perspectives.

## Energy policy review

### Mexican antecedents

The integration of renewables into the Mexican energy mix has had being driven through several plans and actions, from big scale projects, through sustainable housing legislation (the green mortgage[45]) and finally towards grid interconnection. During the period 2007-2012, wind was the preferred renewable energy technology by the government because its cost was highly competitive (SENER 2009). Currently, more and more technologies are becoming cheaper, in a way their comparative cost of production and initial investment competes fiercely to some fossil-fuel commercial technologies (Pentland, 2014). Before the new electricity industry law, the public electric service allowed private companies and the public to produce their own electricity in different modes, opening a wide range of investment opportunities (SENER 2009). To allow that, the Mexican government set a group of policies and programmes, based on net metering (still valid). In 2001, the special programme of renewable energy implementation created the *grid interconnection contract for renewable energy sources*, allowing RE producers to tie their systems to the national grid. Besides, CFE created its "energy bank", with the intention to avoid storage costs amongst small scale RE producers (SENER 2009; SENER & GIZ 2012). Apparently the former programmes created during the last decade are not changing drastically with the new law in place for those who signed contracts before the reform, however important structural arrangements are being prepared to boost the usage of renewables in a national level in the years to come (DOF 2014a).

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[45] The green mortgage is offered by the Mexican government to all real estate developers who employ ecotechnologies in social housing (SENER/GIZ 2006).

## The new electricity industry law

The law was introduced in 2013 and promulgated in 2014 with a group of secondary laws that support the model in transition (from a closed energy market to an opened one). The fully implementation of the law is planned to be ready by 2018 and during this time the ministry of energy and the respective government bodies are responsible to generate the necessary changes to reach an independent electricity market.

### *System and market description*

As said before, the main intention of the law is to create the structure of a free electricity market in Mexico, promoting public and private investment in specific activities the industry comprises (generation, transmission, distribution and commercialization of electricity); all under surveillance of the state. Basically, the state is creating a market where different actors will perform for the sake of the National Electricity System (NES). The NES' entails a broad range of actors, including those performing into the market and other non-direct and adjacent actors as equipment and fuel suppliers. The planning and control as well as the public electricity transmission and distribution will remain under governmental control; however, the possibility to generate strategies with private and public investors is opened to the government. The wholesale electricity market (from now the market) includes the trading of electricity and other products, being based on a free market economy concept and being coordinated by a new governmental body, the National Energy Control Centre (in Spanish CENACE). Into the market, the different actors are allowed to make free transactions and negotiations but with some basic parameters, called "market basis". The tradable assets in such negotiations are electricity, power, Clean Energy Certificates (CECs), related services and other associated products. To make it possible, the market is subdivided in five different categories organized by the type of products:

- Short term market
- Power balance market
- CECs market
- Transmission financial rights tendering platform, and
- Large and medium term tendering platform (DOF 2014a; CRE n.d.)

The market actors are also subdivided in categories as: generators, suppliers, traders, basic service users[46] and qualified users[47]; and all of them are dependent in some way to the CENACE and the market. The next figure exemplifies how the actors are related into the market and their position around the CENACE.

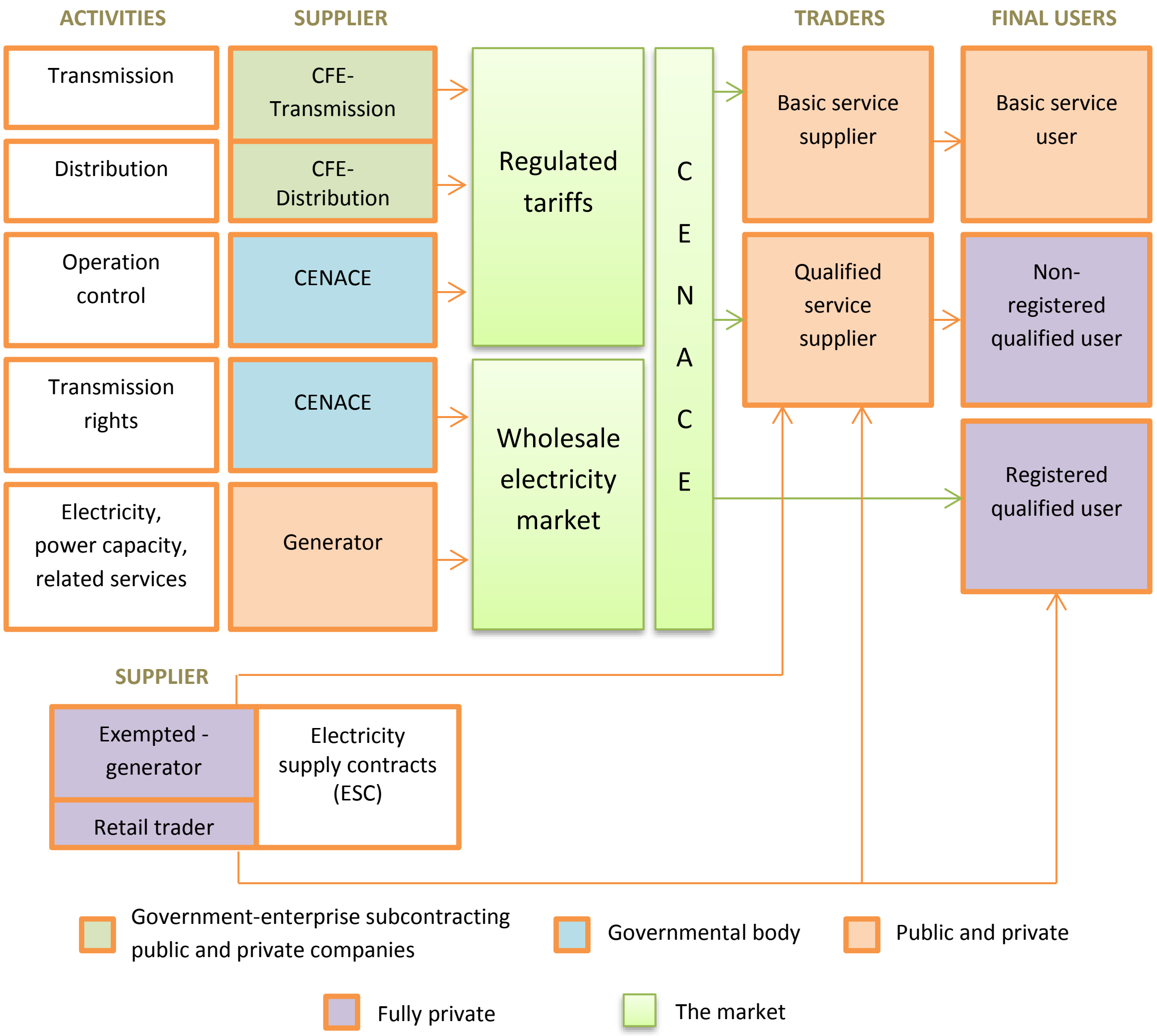

Figure 10. Wholesale electricity market structure (Bierzwinsky et al. 2014).

As could be seen in Figure 10, the wholesale electricity market hinges around the CENACE and its activities, where most of transactions has to pass through and those that do not (the ESC) have to be authorized by the centre. The activities into the market are separated by government and

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[46] Basic service users are those final users who are not registered with the CRE and consume less than 2 MW before August 2016 and less than 1 MW after that date (CRE n.d.).

[47] Qualified users are final users who are registered with the CRE and consume more than 2 MW before August 2016 and more than 1 MW after the same date (CRE n.d.)l

private with their respective combinations. For example, transmission and distribution are exclusive to CFE, however, the possibility to hire a company to develop such jobs are opened to the commission. This is not the case for the market's operation which is under CENACE supervision. On the other hand, free-generation, retail trading, qualified supply and its users are predominantly private[48]. In the case of generation, basic service retailing and basic final users the mix amongst public and private entities are unleashed (DOF 2014a; CRE n.d.; Bierzwinsky et al. 2014).

In order to exemplify how the market works it will be described a part of it called "short term market" which works as any free market with demand and offer but with variable cost differentiation. This means, the dispatch order depends on variable costs and start from the lowest to the highest to be dispatched; being the last variable cost dispatched the final price to be paid to all generators. This short term market is going to be constituted by other *two submarkets*: the "*one day in advance market"*, in which electricity, power and other services are traded one day before consumption; and, the "*spot market*", where such products and services are traded for being used in the same day (one hour before)[49]. As mentioned previously, the ruling institution in charge to organize the market and the dispatch order, maintaining the system' stability is the CENACE.

Additionally to electricity, the market offers *separated products* as *power* and *CECs, which* can be traded into their respective submarkets and are assumed to help generators to cover fixed cost of operation. The reason to think that is because the final consumers, traders and suppliers are obliged to purchase power and CECs proportionally to their demand, covering cost of operation and investment of new plants and plants with clean technologies. Such costumer compromises are expected to increase over the time, aiming to transfer all consumers the commitments the country has made regarding clean energies integration (DOF 2013; DOF 2014a; SENER 2014a; El Economista 2015; CRE n.d.). One advantage about the new legislation is the *Electricity supply contract* scheme that consents free negotiations amongst actors without being driven by market terms and allowing independence between generators and customers (CRE n.d.).

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[48] Some governmental companies and bodies might be considered qualified users due to their nature (DOF 2014a; CRE n.d.)

[49] The spot market will be started in 2018 (CRE n.d.).

Regarding rights and constrains about trading, not all actors have the same. For example, *generators*[50] are free to trade and participate into the market as well as participate in governmental medium and long term bidding process. Also they can agree contracts and sell electricity and other related products to qualified users and qualified services suppliers but they cannot trade electricity directly to basic users. On the contrary, *exempted-generators*[51] do not require permission to electricity generation from CRE. Nevertheless, they can sell their electricity and other related products to *basic service suppliers* but without participating directly into the market. *Qualified users* are allowed to buy into the market or contract a supplier of qualified services for the task; additionally, they can sign contracts with generators in the terms they consider optimum. In case a qualified user prefers regulated prices rather those in the market, it is allowed to acquire services from a basic services provider. Exists also the possibility qualified users do not register themselves into the market and for that exists a supplier category, called *qualified services supplier,* who is in charge to engage contracts with non-registered qualified users in order to represent them into the market. The *basic user* is the one who is not registered as a qualified one and has no chance to participate into the market; normally low and medium tension users are in this category. The way these users access electricity is through a *basic services supplier*, who represent many basic users into the market and engage electricity supply to them in medium and long term tendering processes (DOF 2014a; CRE n.d.).

Besides electricity there are other related products[52] offered into the market and all of them should be available for trading. The only product final users may offer into the market is the controlled demand, what means, they offer scheduled non-demand for certain period of time (commonly during peak times) in order to stabilized the NES. Such requests are made directly by the CENACE (DOF 2014a; CRE n.d.).

### Renewables into the law

Going to the core interest of this work, it is important to mention the status of renewable in front the law and what are the considerations to them. Into the regulation, renewable energies are considered clean energies as well as other technologies as carbon sequestration and natural gas; this, without distinction amongst them and therefore supported equally through CECs and the

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[50] To be considered generators energy producers may count with electric generation plants above 0.5 MW and may sign a generation contract with the CENACE (DOF 2014a).

[51] Exempt generators are those who count with plants with less than 0.5 MW of capacity (DOF 2014a).

[52] The related products can be classified in: power, CECs, transmission financial rights, other services and controlled demand (DOF 2014a; CRE n.d.).

dispatch order. The latter is considered a support to renewables and clean technologies because some of them have lower variable costs than fossil fuel technologies and theoretically, they are expected to be dispatched first due to such costs (if they can generate electricity at the required time). In that case, first dispatched plants are going to be paid with a higher variable cost than they have, being always the latest dispatcher cost the selected one. To increase that over the time, the government has set a group of ascendant goals for short and medium term. The nearest is to achieve 25% of generation by 2018, this considering in 2013 just 15.4% of plants were producing electricity with non-fossil fuel technologies. The rest of goals are even more ambitious: 35% in 2024, 40% in 2035 and 50% in 2050 (SENER 2013c; DOF 2014a; CRE n.d.). Regarding CECs, each MWh generated with clean energy and traded into the market might receive one tradable certificate that can be used by users and suppliers to prove the SENER the required percentage of clean energy consumption. Those who have obligation to achieve certain percentage of clean energy are: basic and qualified services suppliers, registered qualified users, isolated supply users and all interconnected load points that consume a percentage of non-clean electricity. Additionally, all actors into the market are allowed to buy CECs voluntarily, but it is necessary to be registered as a voluntary entity. The initial goal of CECs is going to start in 2018 and was set three years before (2015), as the law mandates for each year to come. The trading process can be into the CECs market, in auctions or in an annual clearance sale (DOF 2014a; CRE n.d.).

Another option for renewable energy implementation is the *isolated supply,* which is a classification of final user who decides to generate or import electricity by itself instead of buying it into the market. The isolation consist this type of user has no permission to use the national grid to transmit electricity, nevertheless, it is allowed to be interconnected for selling and buying electricity in case of need or surplus. In that case, the electric plant may be registered as generator or exempted generator (DOF 2014a; CRE n.d.).

### *National content and the new law*

Regarding to the local content, it could be said, the new structure of the electric market in Mexico and the law intend to attract as much private investment as possible. To make it possible, the government has mandate different ministries to generate platforms to support private and public investment all over the sector, but with special attention to the development of the local industry. Local industry integration is an important and constant point mentioned into the law, however, in order to start a competitive market, the law itself recognizes the importance of foreign technology and investment, as well as the technology transfer and assimilation. To generate positive conditions for technology transfer, the law suggests international and local alliances as a figure that might help international and local companies to access financial and training governmental supports. Unfortunately, the law does not specify an obligatory national content for project, which can generate confusion and undesirable competition results if lock is not put into action. Additionally, another strategy which is fundamental to the implementation of the reform is the integration and development of specialized education and research. As a consequence, the government has created an especial education programme to attend particularly the need of qualified people into the sector; encouraging higher education institutions and companies to access such funds by creating internal programmes. In order to expand the sight of the policy structure surrounding the reform, next section reviews and analyzes briefly some secondary laws and programmes related to it.

## Energy secondary laws and programmes in Mexico

In general, the way policy structure goes in Mexico is from the ambiguous (the constitution and general laws) to the specific (norms and manuals) and in the same way the energy policy structure goes for itself (SFP 2011). In order to generate an effective policy implementation, the current administration created a general strategy that interprets all laws above and commands all strategies and programmes below; called the National Development Plan (NDP) (see Figure 11). For the case of electricity, the first in order is the before commented law that interacts with other laws[53] to generate plans, strategies and programmes[54]. One companion law which is relevant for this work is the Renewable Energy Usage and Energy Transition Financing Law (REUETFL[55]), which represents the foundations of RE in Mexico (DOF 2014a; DOF 2013; SENER 2014a; SENER 2013a;

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[53] Federal Strategy Law (FSL), Federal Public Administration Law (FPAL), Science and Technology Law (STL), Hydrocarbon Law (HL), Bioenergetics Development and Promotion Law (BDPL) and the Renewable Energy Usage and Energy Transition Financing Law (REUETFL)

[54] Energy Transition and Sustainable Energy Usage National Strategy (ETSEUNS); National Energy Strategy (NENS); Sustainable Energy Usage National Programme (SEUNP); Renewable Energy Usage Special Programme (REUSP); Strategic Programme for Specialized Human Resources in Energy (SPSHRE)

[55] The REUETFL has amongst its commands: define the parameters for energies to be considered as renewable; create the renewable energy national catalog and commands its update; mandate the Energy Regulatory Commission (ERC) to periodically set a goal for renewables into the NES; command ministries to facilitate the inclusion of renewable energy equipment through economic policies; instruct the NES to receive electricity surplus from self-supply users (under certain conditions); create a trust devoted to energy transition and renewable energy implementation; coordinate international financing; and, mandate the federal government to update the special programme (REUSP) for this law .

SENER 2014b; SENER/SEP/CONACYT n.d.). Figure 11 shows the structure in which laws, plans, strategies and programmes contribute to the energy policy in Mexico.

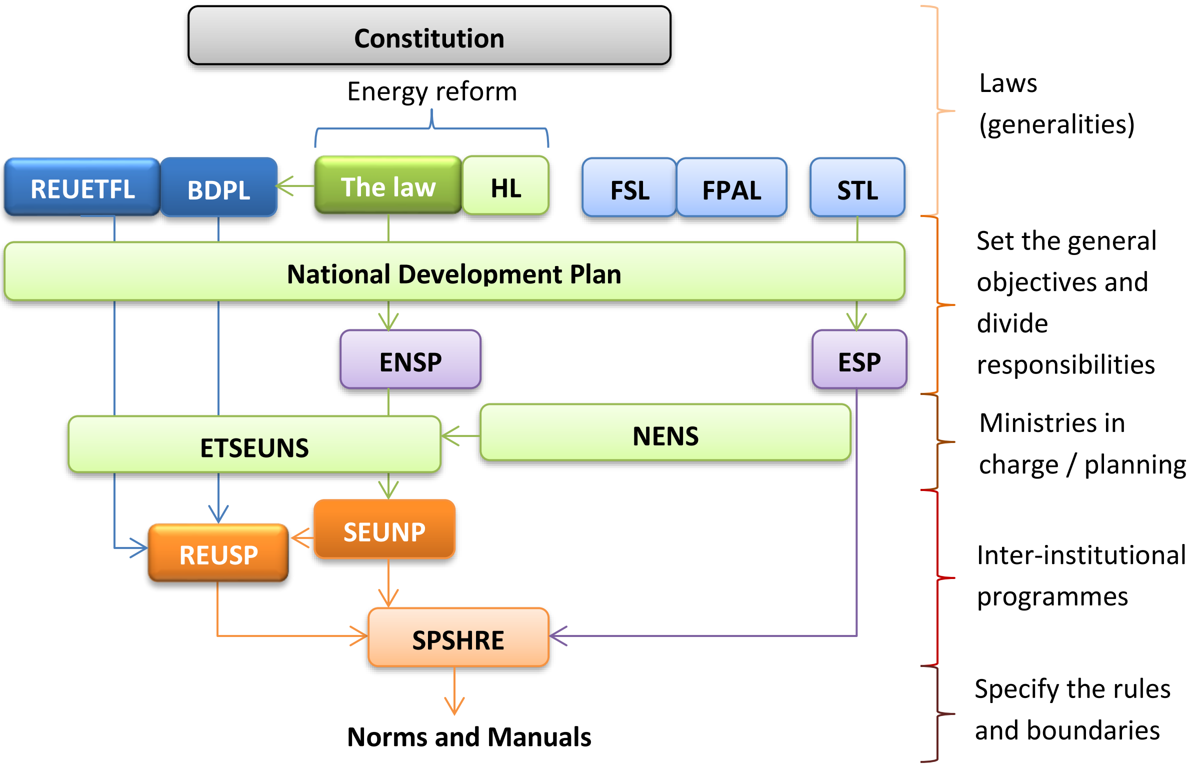

Figure 11. Top-down energy policy structure in Mexico, (own authorship).

As can be seen in the figure above, there are many parts of the energy policy in Mexico related to the recent reform, including administrative, educational and hydrocarbon components. Despite most of them mentioned renewables and the electricity sector, not all laws, strategies and programmes shown in the figure are relevant to this work. The reason of this is because not all of them specify deeply enough concerning implementation issues about renewables, handling other aspects of the policy not concerning to this work. For example, in the Energy Sector Programme (ESP) which is part of NDP, are set general objectives and actions but no specificity is made up (SENER 2013c). On its side, the National Energy Strategy (NENS) points out the problematic to be faced in the next years (until 2027) and suggests the way to overtake such challenges (SENER 2013a; SENER 2014a). Together these documents are the basis for the strategies which implies funding and responsibilities amongst institutions, however, they do not go further into solutions. The first one in stablish and mention actions is the Energy Transition and Sustainable Energy Usage

National Strategy (ETSEUNS) that fixed the way (specific objectives) the budget must be divided through a trust mandated by the REUETFL (SENER 2014a).

Contrary to the programmes and strategies mentioned before, the special and strategic programmes are the most active ones in the structure, specifying actions, institutions, timing and resources. For example, the Renewable Energy Usage Special Programme (REUSP), a mainstay of RE implementation, mentions all regarding renewables implementation in Mexico and the goals[56] the current government might achieve (SENER 2013b). Another important component related to energy transition and technology transfer is the Strategic Programme for Specialized Human Resources in Energy (SPSHRE) that has the general objective to generate specialists that support the new (opened) energy sector and the reform. The reason this special programme takes such high relevance is because the sector will need 135,000 experts to succeed in the implementation of the reform (within the next two years) (SENER/SEP/CONACYT n.d.).

## Evaluation of the energy policy in Mexico

As mentioned before, the perspectives of Lundvall & Borrás (2013) and Schmidt & Huenteler (2016) are considered appropriate as comparison base for the methodology of assessment in the present work. The intention is to generate a matrix that contrasts the current policies structure with the stages and steps described by already mentioned authors and evaluate them considering the drivers, strengths, opportunities, barriers and weaknesses of policy and business models mentioned by Engelken et al. (2016). So, next tables are an assessment effort to evaluate the leverage effect policies have over RE implementation in the opening electricity market. The evaluating scale goes from 0.0 to 2.0 and each pace has an influence value level over the sector: 0.0, none; 0.5, low; 1.0, neutral; 1.5, good and 2.0, optimum. Additionally, all results are accompanied with an arrow that describes tendency (positive, neutral and negative) regarding policy implementations in the near future. See Annex 1 for more detailed information about the methodology of assessment.

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[56] The goals set for the current administration by the REUSP are: to report the achievements regarding renewables and set the new actions; to divides tasks amongst programmes, institutions and ministries; to defines interconnection projects for areas with RE potential, called “open seasons”; to establish Mexican Energy Innovation Centers (MEIC) into the country; and, to set indicators and indexes for evaluation purposes (SENER 2013b).

| Policy steps | Stages of catching-up | Components | Results | Considerations | Sources |
|---|---|---|---|---|---|
| Scientific policies | Basic science | Schools and Universities | 1.5 → | 278 technic schools/ 4,111 universities and technological universities/ 2,199 Postgrads. | (CIEES 2015) |
| | | Professionals and technicians in formation | 1.5 → | 159,703 technician students/ 2,997,266 university students/ 237,093 postgrad students. | (CIEES 2015) |
| | Specialized science | Universities and postgrads | 0.5 ↑ | Universities have starting to open programmes associated with RE, but unfortunately are not enough and several problems have been fund in relation with them. | (CAMPOS GARZA 2016) |
| | | Specialist (professionals and technicians) in formation | 0.5 ↑ | 135,000 professionals are needed in the next 2 years. | (SENER/SEP/ CONACYT n.d.) |
| | | Promotion and funding | 2.0 → | Special trust CONACYT-SENER. | (SENER 2014b) |
| | | Scientific support in Decision making | 1.0 ↑ | In the federal level yes, but at state and municipality levels is almost inexistent by now. | (SE 2014) |
| **Scientific policies leverage effect** | | | **1.17 ↑** | | |

Table 10. Energy policies' leverage effect over the first step of knowledge.

Table 10 shows basic science in Mexico is well stablished to support the entrance of a new industry in a simple level and may help to impulse applied sciences in a specific field. By now specialized science in the renewables field is in formation and is still weak. However, the governmental support is strong and aims to impulse specialized education in few years. The urgency of creating specialized human resources (HR) in a very short period of time may create a problem because such urgency may push schools and universities to create educational programmes and professionals with lower standards the energy reform needs; endangering its implementation and success. Despite these problems, the leverage effect of scientific policies in Mexico is considered to have a good influence value and tendency; growing from a neutral to a good reform implementation if the governmental support concretes its goals. It is important to highlight, a good scientific policy implementation and HR formation are essential for the success of the future integration of renewables in Mexico because without professionals and knowledge cannot be possible any further plan.

| Policy steps | Stages of catching-up | Components | Results | Considerations | Sources |
|---|---|---|---|---|---|
| Technology policies | Technology deployment | Existing market | 0.5 ↑ | A young market with a high goal in few years (35% by 2024). Law's misconception; considering some technologies and capacities as clean when specialized laws do not. Current high electricity subsidies jeopardize capacity addition. | (SE 2014; SENER 2013b; DOF 2013) |
| | | Professionals and technicians available | 1.0 ↑ | 135,000 professionals are needed in the next 2 years, but current professionals and technician can uptake the challenge. | (SENER/SEP/CONACYT n.d.; SE 2014) |
| | | Specialist available | 0.5 ↑ | 135,000 professionals are needed in the next 2 years. | (SENER/SEP/CONACYT n.d.) |
| | | Grants or facilities | 2.0 → | Three national trusts; fiscal incentives and several programmes. | (SE 2014) |
| | Manufacturing | Existing market | 1.0 → | 26 big corporations related to RE, 16 RE components manufacturers and many companies providing O&M. The biggest PV panel producer in Latin America. Low wages in the industrial sector. | (SE 2014) |
| | | Professionals and technicians available | 1.0 → | Existing RE industry has taken professionals and technicians, so existing HR can uptake the challenge, however, investment and knowhow must come to boost the industry. | (SE 2014) |
| | | Specialist available | 1.5 → | Existing RE industry has taken professionals and technicians, so existing HR can uptake the challenge, however, investment and knowhow must come to boost the industry. | (SE 2014) |
| | | Grants or facilities | 2 → | Three national trust; fiscal incentives and several supporting programmes. | (SE 2014) |
| | Market | National content | 0.5 ↘ | Not specified in the law (subject to corruption). A low percentage might jeopardize the local industry uptaking. | (DOF 2014a) |
| | | Leverage effect | 0.5 ↑ | Small because the market has not started yet (until 2018), but the initial target is in place (5%). | (DOF 2014b) |
| **Technology policies leverage effect** | | | **1.05 →** | | |

Table 11. Energy policies' leverage effect over the second step of knowledge.

Regarding the main objectives of the law and the reforms, which is a combination of technology deployment, manufacturing and the implementation of a new market, Table 11 shows the many efforts the government has set have limited influence in the promotion and implementation of renewables by the moment. One big reason is, electricity and CECs markets are in process to be implemented and such implementation will take time, however, it is expected RE integration will increase at the moment the markets start working at its full. Another aspect that pulls down the leverage effect of technology policies is the lack of specialized human resources which are expected to attend the market and make it better. Of course, it is expected the tendency in HR capacity and amount will increase in the future, helping to fully implement the market in the years to come. A negative influence detected into the group of laws is constituted by vacuums and non-specificities which may disturb renewables integration; being the unspecified national content and the misconception regarding clean energies the most representative ones. Both are prone to be manipulated by government actors and in some cases corruption might get into the equation. Therefore, the leverage effect of these policies is almost neutral, depicting the heavy influence the government still has over the sector and its lack of maturity.

| Policy steps | Stages of catching-up | Components | Results | Considerations | Sources |
|---|---|---|---|---|---|
| Innovation policies | Design skills | Being build | 0.5 ↑ | Mexican Energy Innovation Centers and research centers from universities and governmental institutions (UNAM-IER/IIE-CFE to mention some). | (SE 2014) |
| | Manufacturing | Companies installed | 0.5 ↑ | Good RE manufacturing capacity for a country with low RE integration, as well as good industrial infrastructure. However, such capacity is not enough to compete internationally. | (SE 2014) |
| **Innovation policies leverage effect** | | | **0.5 ↑** | | |
| **Leverage effect of energy policies over the RE implementation in Mexico** | | | **0.91 ↑** | | |

Table 12. Energy policies' leverage effect over the third step of knowledge and RE implementation in Mexico.

The third group of policies is the innovation ones and in that sense policies in Mexico are in a very initial stage but with a good tendency because the governmental support is focusing over research institutes, universities and start-ups, which can be considered as good. The current infrastructure in Mexico (industrial and services) is quite competitive in terms of production and quality standards, which might serve as basis for the creation of a RE manufacturing spot, attending local and regional demand. However, such idea is fairly challenging if global competition is considered. In general, the expectation of innovation policies in Mexico, as any part of the world, is assumed to become positive if the right factors and actors take their place on time.

The final leverage effect of current energy policies in Mexico was found to be lower than neutral but with a positive tendency that could be improved in the near future. Tools are now in place and seem to be quite attractive for investment, but in order to succeed is very important the institutions in charge must be safeguarded from corruption and political usage in order to achieve the right implementation of the market and to increase available HR.

## Brief wastewater treatment policy review

As explained in the first chapter, water policies and agents in Mexico are structured in levels and the differences between clean and wastewater are specified in some norms and laws that differentiate their management. On the top, there are three basic laws that complement the constitution mandate to protect the environment: The Environmental Protection Law (EPL), the Federal Water Rights Law (FWRL) and the National Water Law (NWL). All of them, in special segments, refer specifically to wastewater management and its importance for the environment and society. Therefore, each federal administration has to generate a Hydrologic National Programme (HNP), as part of the NDP, in order to accomplish them. Additionally, other water care programmes such as the Infrastructure National Programme (INP) complement the HNP in its implementation part with funding and administrative support, amongst others. In terms of standards and parameters, as the operative part, exist four Mexican Official Standards (in Spanish NOMs) that set the limits of wastewater management and its byproducts[57], giving operational guidance to the entire sector (De la Peña et al. 2013). Then, the practical part of the whole policy in terms of support devolves upon seven special programmes, that promote better operation practices, equipment update and sustainability amongst plants; this, with the aim to handle problems as water scarcity, pollution and their respective social and economic impacts (DOF 2009; CONAGUA 2014c; SEMARNAT/CONAGUA 2014; SEMARNAT/CONAGUA 2015). Please see next figure.

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[57] Can be considered Byproducts of wastewater: depolluted water and bio-solids

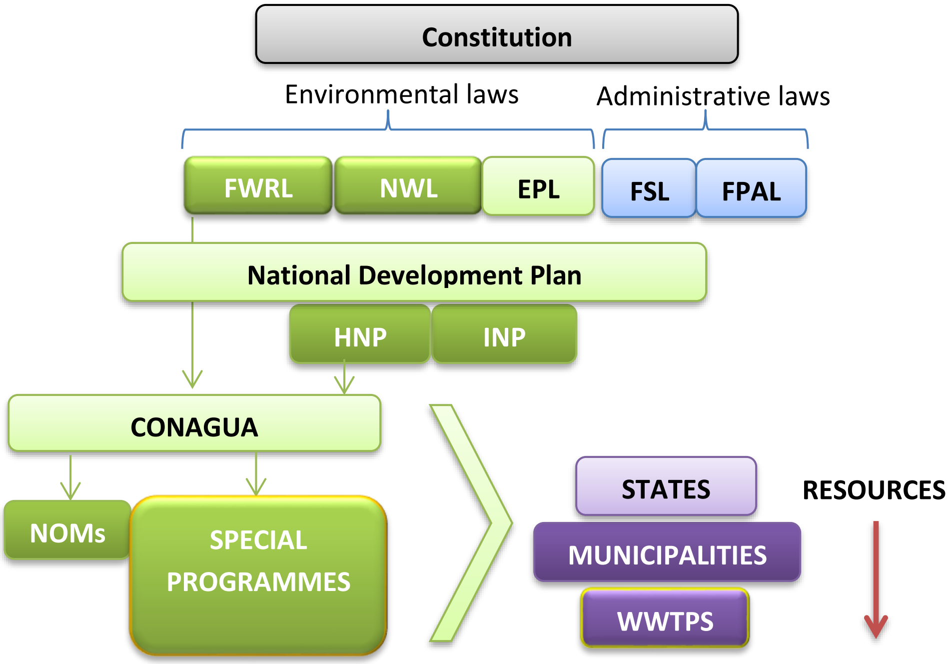

Figure 12. Top-down water policy structure and actors in Mexico (own authorship).

Here is important to highlight, in terms of policy and laws the present work cannot go profoundly over wastewater policies due to its main focus is energy policy. Therefore, the present section will remain shorter than the previous one because specificities and the water structure will not be explained in depth. Nevertheless, the review is considered important because the study of the legal framework of wastewater treatment will give the "dos and don'ts" of technology implementation proposals.

### Wastewater special programmes

As mentioned above, the special programmes are the practical tools of the government to support and finance the water sector in Mexico and all are coordinated by CONAGUA in agreement with other multilevel actors[58]. These seven special programmes cover all water issues into the country (including wastewater) and some of them can be considered as generalists because they support all related to water and few of them are specialized in specific topics or areas. These tools are mainly funded by federal, state and municipal means but sometimes national and international institutions as well as the private sector contribute with them (CONAGUA 2014c). The tools are listed below:

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[58] Federal institutions, state governments and municipal actors are considered as multilevel actors.

- ***Urban Zones Water and Wastewater Programme*** is a tool the federal government in collaboration with states governments uses to support planning, construction and rehabilitation of potable water, sewage and wastewater treatment infrastructure in urban areas[59]. This programme also supports efficiency actions that aim major population attention or upgrade of services. In 2013, the total amount invested was around 443 million euros and amongst the investment 10 WWTPs were constructed and 8 refurbished (CONAGUA 2014c).
- ***Water Operators Efficiency Upgrade Programme****.* In this programme CONAGUA and the World Bank support together water operators with a total investment of 100 million euros, supplementing the prior programme with two *components*: the *first*, supports data generation projects for local operators with the aim to increase available data into the sector; the *second*, that supports directly the efficiency of performance of operators and promotes financial self-sufficiency. This is divided in three *subcomponents*: *technical assessment efficiency*, which serves as a previous study (fully paid) to achieve financial support in the next subcomponent; *Classic investment*, in which direct finance funding serves to upgrade the efficiency of performance, and; a *pilot goal's payment* subcomponent, in which good achievements in terms of efficiency are rewarded (CONAGUA 2014c).
- ***The Rights Payment Reimbursement Programme*** is a direct tool that intends to boost investment over services improvement by reimbursing payments related to water usage rights; this, as long as operators commit themselves to invest the same amount into efficiency and infrastructure upgrading. This programme is a very accessible financing source for water operators because can be directly and constantly accessed by them (four times along the year). The governmental budget is 96.81 million euros each year and 22.3% of the total has been applied into WWTPs (CONAGUA 2014c). This programme also allows to use 30% of the reimbursement to pay pumping electricity expenses (DOF 2014c).
- ***Water Operators Modernization Porgramme****.* This programme co-works with the infrastructure national fund to directly support water operators in cities with more than 50 thousand inhabitants. Its funds are characterized for being: non-refundable[60], in

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[59] In Mexico the digit to differentiate urban (up) and rural (down) areas is 2,500 inhabitants (CONAGUA 2014c).

[60] The non-refundable resources are given with more facility to operators that have efficiencies above 75% and in case are less operators might generate an internal diagnosis and planning study to access the means.

association with the private sector and with the aim to increase service's coverage and efficiency. As part of its objectives the programme aims to consolidate water operators, increase efficiency and commercial performance, update technology, achieve self-sufficiency and protect the environment; this, with a special focus on WWT. BANOBRAS, the country's development bank, funds the trust with 226 million euros each year and the type of projects able to be funded are: management improvement projects, water supply projects, wastewater projects and big scale projects. (CONAGUA 2014c). In specific for wastewater operators, the programme subsidize biogas investments and projects with up to 50% of support, covering a wide range of expenses: from feasibility studies until implementation stages and construction (SEMARNAT 2012).

- ***The Wastewater Treatment Federal Programme*** is the government instrument to increase wastewater treatment into the country through fiscal benefits[61] at the municipality level (non-direct). In order to access it, municipalities and the basins administrative regions have to submit an *action plan* to CONAGUA to be fundable; and in such case, CONAGUA and the federal tax collector agree the amount to be exempt for each municipality. This special programme which is devoted to improve processes in WWTPs and do not allow investment into other related processes. In 2013, an amount of 9,686.25 million euros was devoted to the programme (SEMARNAT 2011).
- ***Rural Areas Water and Wastewater Programme*****.** This tool is focused on supporting planning, construction and rehabilitation of water infrastructure in rural areas in collaboration with the community. In 2013, the total amount invested was around 181 million euros, benefiting 633 small towns around the country and providing local temporal employment to the community members (CONAGUA 2014c; CONAGUA 2014b).
- ***The Mexico Valley's Basin Sustainable Programme*** attends needs and problems regarding water and wastewater management of the capital; including construction, refurbishing and efficiency tasks. This programme is very similar to the urban programme but considering problematics of a megacity (CONAGUA 2014c).

Regarding governmental support to the water sector it is possible to identify two *types of support*, direct and indirect. The *direct* type can be described as the one in which the own operator can

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The same programme finance 50% with non-refundable means the studies mentioned previously (CONAGUA 2014c).

[61] Fiscal benefits are duties exemption or fiscal credits (CONAGUA 2014c).

begin a process for financial support and the *indirect* one, is a support tight to a governmental development plan. The first one is considered by this work as the most accessible one because to be awarded the requirements just must be accomplished and political will cannot interfere into the process. Another advantage identified is, the direct type may better represent and address particular needs of operators because they themselves generates the investment proposal. On the contrary, the indirect support has to compulsory goes through governmental plans or strategies in order to be accessed and not everyone will able to be into the strategy at the same time. One advantage is indirect programmes have more resources than direct ones because they are very focused on infrastructure and therefore they cannot spread the resource amongst all. In this sense, the next table presents all programmes and classified them in order to identify the most useful for the purpose of this work. The table is composed by three categories of support that depict how the programme interacts. The first type is *coverage* which has *three forms* to be: the *Generalist* which describes programmes that consider all related into the water sector and without distinguishing subsectors or places; *focused* is a type of programme which is specially devoted to an area or subsector, and *pointed*, a generalist type programme that has a segment which is focused specifically over area or subsector. The support type (direct and indirect) has been already explained above. The energy type is the one that serves to identify the usefulness of a programme in terms of support towards energy expenses and investments. This sort has three ways to be: *possible,* when the programme does not exclude energy infrastructure investment; *non-possible,* a programme that specifies do not support energy investment at all; and the *focused* one, which has a special segment that mentions energy expenses.

| No. | Programmes | Coverage | Support | Energy |
|---|---|---|---|---|
| 1 | Water Operators Efficiency Upgrade Programme | Generalist | Direct | Possible |
| 2 | Rights Payment Reimbursement Programme | Pointed | Direct | Focused |
| 3 | Water Operators Modernization Porgramme | Pointed | Direct | Focused |
| 4 | Mexico Valley's Basin Sustainable Programme | Focused | Indirect | Possible |
| 5 | Rural Areas Water and Wastewater Programme | Pointed | Indirect | Possible |
| 6 | Wastewater Treatment Federal Programme | Focused | Indirect | Non-possible |
| 7 | Urban Zones Water and Wastewater Programme | Pointed | Indirect | Possible |

**Table 13. Special programmes classification.**

As could be seen in Table 13 the most accessible ones in terms of ease might be the second and third when the commitment is energy expending. Both programmes allow operators to directly subscribe projects or plans to access support towards actions they themselves propose. On the other hand, a programme completely closed to energy expenses is the sixth one, which is devoted exclusively to increase treatment. The rest of programmes are opened or do not forbid energy expenses at any sense, therefore energy related projects can apply to them.

## Conclusion

Environmental and energy policies face many implementation problems and challenges, especially those related with economics and interests strive. The aim of many countries is to achieve robust policies accompanied by a pure economic rational allowing effective actions towards implementation. Unfortunately, the so called policy implementation gap might appear by the hand of manifold negative factors which are very common in emerging economies, cities and sectors experiencing expansion and policies adaptation processes; being manly the lack of knowledge the main reason starting the gap. In this regard, Mexico is facing a process of policy adaptation and technology catching up in the current electricity reform and other environmental actions as a nation. The current braking up of the former electricity market in Mexico has pushed the entire country to an adaptation process in which the new legislation has been tried for the first time and new models are waiting to be fully introduced. The new electricity market arrangement seems quite good for renewables integration in a general perspective (down in paper) and initiatives such as the variable cost rule for dispatch, the electric supply contract and the compulsory percentage of clean energies will definitely help renewables to be integrated in all sectors. However, severe misconceptions in the term of clean energy may lead unbalances in the share of real clean technologies if some locks are not set. So, if the electricity reforms are seen as a part of an energy policy structure, the possibility of an implementation gap to appear is quite high because the lack of knowledge and expertise in that regard is high as well. The analysis made by this work says science policies in Mexico are strength enough to bear the reform, nevertheless, specialized science and professionals are essential to fully implement it and the fail to generate them may possibly endanger the entire reform. In this respect, the present work considers, the government did not follow a logical sequence of steps to start the reform because is trying to implement scientific policies at the same time to deploy technologies and not before. The leverage effect of the entire policy structure seems to have a low influence but with a positive tendency because not all parts of the new market are in operation to date. The wastewater policy analysis made by this work considers the special programmes group as useful for renewable energy implementation into the sector. This is because the majority of programmes allow investment over energy projects and in some cases support towards renewables is quite specific. So, it can be said, the current policy structure in energy and wastewater allow and encourage the integration of renewables over the wastewater sector, nevertheless, many actors and actions must be well driven by real experts in order to succeed.

# Economics - Chapter 3

## Introduction

Renewable energy as part of an economy, as seen in chapter 2, has manners to be priced and this is one of the most important parts of technology inclusion because technical, environmental and policy aspects are put together to generate a cost; being possible to compare renewables and other technologies at the same level. This aspect takes relevance to renewable energy implementation because at this point the right sale and finance strategy is set in accordance to compete into a market, which is very challenging. Common costs and availability of resources are part of cost accountability of renewables, however, issues as local market rules and financial access are in some cases decisive to the feasibility of energy projects. This chapter focuses over economics of renewable energy in a brief review, with the intention to point out the necessary factors to generate a commercial and economically feasible renewable energy project.

## Basics

Renewable energy counts with many technologies into its classification and each of them may compete with current nuclear and fossil fuels technologies in terms of energy supply. The type of sources and technologies involved are quite numerous and current research and development of technologies is increasing in many countries since energy needs and environmental concerns grow with them (The Open University 2012). As part of an economy, renewables face competition and push to gain a fraction in the global energy scheme. Governments and organizations do their part, establishing policies and supports that help renewables to guarantee a place in international and national markets. To make it possible, economic tools has been used and in some cases specialized tools have been created to evaluate renewables' performance in a right way. As a consequence, pricing and cost calculation have become essential for technology inclusion but particularly in highly competitive markets where investor's doubts should be calmed (Nelson 2011; The Open University 2012). The importance of economic calculations in liberalized energy markets is quite high, because competition amongst different technologies is tough and renewables governmental supports tend to be less; becoming the return of investment the driver as in any business. Technical, environmental, policy as well as other main aspects are required to be known at the time of economic evaluation and concepts such as Life Cycle Costs (LCC) are well recommended by the literature (Nelson 2011; Venkatesh & Elmi 2013; Gatzert & Vogl 2015; Khatib & Difiglio 2016; Engelken et al. 2016). To deal better with this concept and other economic ones, it is important to mention, at least in an introductory way, *basic concepts* of energy economics which are essential for this type of evaluation.

Economic evaluation of a project offers guidelines to investors and developers whether a renewable energy project might be *economically feasible* or not, and such feasibility is determined when the overall income compared to its general costs exceeds them with a desired margin. The moment, during the lifespan of a project, when earnings meets expenses in monetary terms is called *payback time* and it is one of the most popular forms to evaluate the economic feasibility of a project. Commonly; the shorter the period the better the payback time, and also, the bigger the initial cost the longer the period of wait. The calculation of the payback time helps to know the period in which the initial investment will be repaid and if that is acceptable in investment terms. In this regard, literature says, periods from 5 to 7 years are quite acceptable and longer periods should be seen with caution by the investment side. Therefore, the banking sector sometimes have special departments to evaluate energy projects because normally such projects exceed acceptable periods. This simple calculation is a tool that assists preliminary judgment in economic feasibility terms but an investment decision cannot rely on this calculation because is too simple and forgets important factors of energy economics as the longevity of the system and the future value of money (Nelson 2011; Masters 2004). The next equation shows the simple payback period calculation.

$$\boldsymbol{SPP = \frac{IC}{(AEP * €/kWh)}} \text{ (62)} \qquad \textbf{(3.1)}$$

Another important principle towards good investment choices is to consider the time value of money which is an interpretation of the money value along the time. To better understand this, a definition by Investopedia (2016) may serves to clarify: “the time value of money (TVM) is the idea that money available at the present time is worth more than the same amount in the future due to its potential earning capacity”. In other words, the finance principle holds that, provided money can earn interest and loose value along the time and in consequence, “any amount of money is worth more the sooner it is received”. To complete the idea, it must be understood *interest* and *discount rates* are part of this value assumption because are the earning and losing power the money has in present-future-present assumptions. The variations of TVM calculations are:

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[62] SSP: Simple Payback Period; IC: Initial Costs; AEP: Annual Energy Production; $/kWh: value of energy unit from the retailer (Nelson 2011).

**Present Value** (PV): the present value of a future amount of money. $\boldsymbol{PV = \frac{FV}{(1+i)^n}}$ **(3.2)**

**Future Value** (FV): the future worth of the today money. $\boldsymbol{FV = PV\,(1+i)^n}$ (63) **(3.3)**

**Net Present Value** (NPV): the difference between the present value of cash inflows and present value of cash outflows (present and future). Commonly, a positive NPV indicates profitability of a project or investment. $\boldsymbol{NPV = \sum_{t=1}^{T} \frac{C_t}{(1+i)^n} - C_o}$ (64) **(3.4)**

The most important part of time value of money is to assume money will not worth the same as today in the future and vice versa, but we can calculate its value at least to take better decisions regarding investment (Volschenk 2013; Investopedia 2016). Continuing with economics in energy, an important part is to calculate the cost to produce energy to be able to compare with retail prices and other technologies, as well as know if the overall cost will be surpassed by earnings and then make investment decisions. There are two ways to calculate the cost to produce energy: one, the cost of energy (COE) which is an annual based calculation considering initial cost and other lifespan costs divided by the total energy generated in a year, giving €/kWh or €/MWh, and; two, the Life Cycle Costs (LCC) which is similar to COE but considering the accumulated yearly costs and earnings of projects; amongst its results it can be obtained payback time, break-even point and cash flows. The LCC calculation is useful to compare technologies or different arrangements of a system and is well suggested to make buying choices. For more information about COE and LCC equations, please see Nelson (2011). To calculate the LCC or other net present value calculations as *present worth* (PW), it is vital to select an adequate discount rate; this, because such rate determines how the money will increase or decrease along the lifespan of the project. Thus, its selection must be taken with care because an unrealistic discount rate may lead unrealistic LCC results and subsequent wrong investment decisions. The rate can be set by the cost of capital (CC), by a desirable rate of return from an investor or by other suitable rates. For the case of the former, exist a formula to calculate it (Nelson 2011):

$$\boldsymbol{CC = \frac{1 + loan\ interest\ rate}{1 - inflation\ rate} - 1} \qquad \textbf{(3.5)}$$

LCC calculations also can be levelized and that consist in spread homogeneously total costs along the lifespan of a project. The levelized cost might be calculated by the next two formulas in which

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(63) *i* = interest (rate); *n* = Number of years (Volschenk 2013).

(64) $C_t$ = net cash inflow during the period *t*; $C_o$ = total initial investment costs; r = discount rate, and *t* = number of time periods (Investopedia 2016).

the former serves to calculate the PW of the project and the second spread it over its lifetime using the basic formula of capital recovery factor (Nelson 2011; OpenEI n.d.).

$$\boldsymbol{PW} = \frac{(\textbf{total cost for year } \boldsymbol{S}) - (\textbf{total financial benefit for year } \boldsymbol{S})}{(\mathbf{1}+\boldsymbol{d})^{\boldsymbol{M}}} \qquad \textbf{(3.6)}$$

$$\boldsymbol{Levelized\ Cost} = \frac{\boldsymbol{PW}\ \boldsymbol{d}\ (\mathbf{1}+\boldsymbol{d})^{\boldsymbol{P}}}{(\mathbf{1}+\boldsymbol{d})^{\boldsymbol{P}}-\mathbf{1}} \qquad \textbf{(3.7)}$$

It is important to emphasize levelized costs should be compared with other levelized cost as the retail price from the utility and do not compare, for example, with COE which is an annual base calculation.

## Applied economic assessment formulas and models

As mentioned in the past chapters, energy and specifically electricity has to be pass through a complex system before to reach the final user. The steps are not only physical also are tight to policies and trade systems. The accountability of the different steps electricity should pass until reach its final destination is part of the economic analysis an investor has to consider (FSF&M 2014b). The present section present current and recommended economic evaluation tools for project implementation.

### Levelized Cost of Electricity (LCOE)

As mentioned before, life cycle costs calculations are well recommended and especially those that spread the cost and earnings equally along the lifetime of a project. The LCOE is one of the most common and popular models for renewables projects economic evaluation and can be as easy or as complicated the project or the investor require. Cost can be regular, planned, punctual, sporadic, or non-programed, nevertheless, all of them can be discounted to a present value in the LCOE calculation with an appropriate discount rate. The sum of the costs, in the simplest LCOE form, is divided by the assumed total power of the system, giving a cost per energy unit (€/kWh or €/MWh) and for that, it is necessary to count at least with some basic information:

- Discount rate
- Nominal capacity or nameplate capacity
- Productive years
- Net capacity factor, and
- Degradation of the energy system

A more advanced levelized cost formula uses multiple algorithms in which the ratio of discounted lifetime costs is build up by a group of costs, financial and tax assumptions in a yearly basis and then set into a present value; thereafter, the net present value of costs is divided by the discounted lifetime electricity generation. The cost components of a LCOE must consider costs in their different categories (fixed and variable). Next list shows some of them as an example to classify them.

**Fixed costs (more determined by capacity)**

- Capital and financing: the whole cost of building up the plant, including financing costs of it.
- Insurance: plant's insuring cost
- Property taxes
- Fixed O&M: Staffing and other costs apart from operating hours
- Corporate taxes (federal, state or municipal)

**Variable costs (more determined by operation)**

- Fuel cost if is used
- Variable O&M: those costs that are a function of operating hours

The next formula shows, as mathematic function, the way the levelized cost of electricity might be calculated.

$$\boldsymbol{LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}} \qquad \textbf{(3.8)}$$

Where:
$I_t$ = investment expenditures in the year t;
$M_t$ = operations and maintenance expenditures in the year t;
$F_t$ = fuel expenditures in the year t;
$\mathrm{E}_t$ = electricity generation in the year t;
$r$ = discount rate; and
$n$ = system's lifetime

(Volschenk 2013; California Energy Commission 2009; FSF&M 2014b)

Regardless the formula used to calculate the LCOE of a system, one important issue is to determine what could be considered a cost. Here, the economic perspective of a cost may help to understand what is considered a cost and literally says: "the real cost of something it what you must give up to get it”. Consequently, the cost surges from the need and from the decision making to solve that need, making all costs opportunity costs. To be more accurate in cost assumption and selection it must be considered all related costs whatever their nature are (explicit or implicit) (FSF&M 2014b). Something that might guide in this selection could be what Nelson (2011) names as “factors affecting economics”, which are not more than the factors to be considered at the time to purchase a renewable energy system for different scale implementation, next table shows such factors.

| Factors | | Factors |
|---|---|---|
| • Load (power) and energy | | • Emergency services and repairs |
| • COE from competing energy sources to meet need | | • Major replacement cost over lifetime (e.g., batteries 5 to 7 yr) |
| • Initial installation costs | - Purchase price | • Insurance |
| | - Shipping | |
| | - Installation (foundation, grid interconnection, labor, etc.) | |
| | - Cost of land (if needed) | |
| • Production of energy | | • Infrastructure |
| • Types and sizes of systems | - Warranty | • Cost of money (fixed or variable interest rate) |
| | - Company (reputation, past history, number of years in business, future prospects) | |
| • Renewable energy resource | - Variations within a year | • Inflation (estimated for future years) |
| | - Variations from year to year | |
| • Reliability | | • Legal fees (negotiation of contracts, titles, easements, permits) |
| • Selling price of energy produced or unit worth of energy displaced and anticipated energy cost changes (escalation) of competing sources | | • Depreciation if system is a business expense |
| • Operation and maintenance (O&M) | | • Any national or state incentives or taxes |
| • General operation, ease of service | | |

Table 14. Factors affecting economics (Nelson 2011).

## Capital Structure and their evaluation models

Returning to the cost of capital and its relationship with the project, it would be advisable to introduce briefly a *capital structure* explanation to extend the cost concept into a project and also to explain how the cost weight bore by a company or project can affect the economic feasibility of a system. In simple terms, the capital structure defines the selected financing combination of a project by its owners and it can be encompassed by equity and debt or combined with mezzanine instruments. This structure describes the liability of a project and what would be the schedule and order of repayments. This is important to the weight of costs and the calculation of the final cost because interest rates, maturity and other arrangements can also determine the economic feasibility of a project; in other words, helps to understand and calculate if the project will be strong enough to bear its own cost of capital (FSF&M 2014c).

For the case of *equity instruments*, the cost of capital or the expected return have not an impact into the levelized cost calculation, this, because they do not have maturity and the returns depends on the ability of the project to generate profits (post payback time). However, they do have an important weight in the final levelized cost as a part of the overall costs, when a Weighted Average Cost of Capital (WACC) of a project is calculated and because sometimes a portion of equity is required by financial institutions. In opposition, *debt instruments* do have maturity, cannot be avoided (do not depend on project's profits) and their cost must appear into the final cost calculation because three main reasons: one, financial costs are constant and periodically spread along the maturity time; two, interest rate of debt modifies the net present value of the cost of capital; and three, the interest expense in some cases is tax deductible, in other words, reduces the profit before taxes and is called "tax shield" (FSF&M 2014c).

### *Weighted Average Cost of Capital*

WACC is a model used to calculate the relative weights of the capital structure components and their corresponding financing costs. The result of this model can be taken as the minimum return (income, saving or profit) a system or a project must produce to satisfy capital providers. Also companies or investors might use WACC calculations to decide whether or not a project is economically feasible. For this work the WACC or the capital structure is important because describe real costs that must be carried and also can help to improve decision making in terms of financing strategies. Next equation shows how WACC can be calculated (FSF&M 2014c).

$$\boldsymbol{WACC = W_d * C_{d,pretax} * (1 - t) + W_e * C_e}\ ^{(65)} \qquad \textbf{(3.9)}$$

## Applied economics in renewables

Renewables have been supported by governments in many countries and as a part of economic policies, supportive tools have been set depending on the energy market type. This has provided incentives for private and institutional stakeholders to invest in renewables under the umbrella of governmental support, which must be considered at the time of economic suitability of projects (FSF&M 2014b; Gatzert & Vogl 2015). The risk and the need of policy supportive tools is a major issue regarding renewables implementation. On the one hand, policy supportive tools must be considered in the economic evaluation because provides incentives and help renewables in their economic feasibility, and on the other hand, due to the clear economic dependency of renewables and the lessening of public support in some countries, the risk political issues can represent increases the attention over them, especially when subsidies are the main drivers of project's economy. Due to the high influence policy supports has over economics the need to identify self-sustaining business models becomes urgent in a highly competitive sector. The ongoing global liberalization of the energy sector and the inclusion of private investors have opened new business models for renewables, but barriers, opportunities and drivers are part of the deal of the liberalization process; therefore, is essential to identify them prior determine the economic likelihood of a project (Gatzert & Vogl 2015; Engelken et al. 2016). Khatib & Difiglio (2016) mention right risk costing calculation in energy technology implementation makes more sense in opened competitive markets than state-safeguarded markets because high capital cost projects (as renewables) are more likely to face financial risks in comparison with fossil fuel power plants. In economic terms, some authors mention the feasibility of a project comes with a right costing process and a life-cycle cost projection. In this regard, LCOE is considered a traditional and suitable method to evaluate technology configuration of dispatchable generation plants, regarding their annualized production costs, and WACC or IRR calculations are considered appropriate to be applied as the discount rate for such calculation (Venkatesh & Elmi 2013; Engelken et al. 2016; Khatib & Difiglio 2016; Gatzert & Vogl 2015).

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[65] Wd: debt`s weight which is the proportion of debt into the capital structure [debt/(equity + debt)]; Cd, pretax: cost of debt (pretax); *t*: profit tax rate; We: equity's weight at market value [equity/(equity + debt)], and; Ce: cost of equity (investors' return expectations) (FSF&M 2014c).

# Conclusions

Besides the technical feasibility in renewables projects the economic one, it could be said, is the final and conclusive; this because integrates technical, policy and economic factors to evaluate the viability of projects. Life-cycle costs calculations and especially the LCOE are essential to the cost and pricing processes not only for renewables also for other energy technologies; what makes this type of tool very practical to compare technologies and energy sources in economic terms. Factors and risks are part of this cost process and their right search and accounting are key for the method. Misconceptions regarding this issues may lead wrong decisions at the time of invest, therefore, special care with trade structure, factors affecting economics and rates should be unavoidable during economic evaluations. The most popular economic evaluation tool is also very accurate in determining issues affecting the economy of an electricity project; this, because the tool can be grown and reduced as logs as the project needs. Hence, LCOE seems very suitable for this work to evaluate in economic terms the new economic and policy structure in Mexico over an applied energy project. Also, as a part of a good economic evaluation a pre economic evaluation that depicts the cost of capital and its structure, in a net present value projection, is required to appear; especially because such evaluation may serve as a discount rate for the project. Therefore, this work considers necessary to simulate an arrangement of expenses and incomes, as any real project must do, in order to generate a probable performance and evaluate it through a model as WACC or IRR. To do so, the economic model has to be sustained by prior technical evaluation of available resources and considering the context in which the project might be.

# Project simulation model - Chapter 4

## Introduction

This chapter is dedicated to collect and analyze the information, models, and methodologies explained in the past chapters, with the intention to apply them into a case study project devoted to explore economic and energetic independency. A detailed description of the selected wastewater treatment plant is made to introduce the case study and set its underpinnings for the assessment. Once the information is together, methodologies of analysis are applied in different steps to drive the model until reach what is considered a plausible proposal. The present chapter uses as a guide the business plan proposed by FSF&M (2014) and also uses, as a reference, the factors affecting economics mentioned in chapter 3. Resources and technologies (heat pumps, hydro, biogas, wind and solar) are evaluated in the pre-assessment section to discard resources and technologies that cannot fit into the plant or fulfill minimum conditions of the project. Then, the selected technologies are evaluated firstly in technological and energy terms and secondly in economic ones. The technical outcome is feed into economic analysis methodologies in companion with assumptions and considerations of the current water and energy policy in Mexico, intending to make close the project's proposal to the reality.

## Plant overview

As part of a technical and economic analysis of a project the present section starts with the description of the location that will serves as a basis for the case study. Technical and operating conditions such as inflow-outflow rates, spatial arrangement, load profile, equipment and a historical energy demand are described in order to stablish the basic parameters for resource and economic evaluation.

### "PTAR – T1" WWTP description

The plant is located into the municipal park Tangamanga 1, which is one of the green areas of the city of San Luis Potosi. Such park is located in the south-western part of the city, near and over to San Miguelito's mountains. The plant T1 is over the initial slope of the mountain, giving to the plant a difference in height of 50 m with respect the sewage collector, which is located in Cuauhtemoc St. 4.5 km away from the plant[66]. The park has 420 hectares majorly constituted by green areas, some roads and buildings (see Figure 13). The green areas maintenance requires

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[66] From the sewage collector to the PTAR-T1 WWTP there are 4.5 km of sewage conduits that follow street shapes that supply the plant with the fluid collected in downtown (Olvera 2016a).

about 12,960 m$^3$/d in order to preserve the vegetation and this entirely depends on the plant's capacity. The type of plant is activated sludge with a design capacity of treatment of 150 l/s and has been operated since 1999 by a private company (PROAGUA) in agreement to the state water commission (CEA) (CEA SLP n.d.; Olvera 2016a).

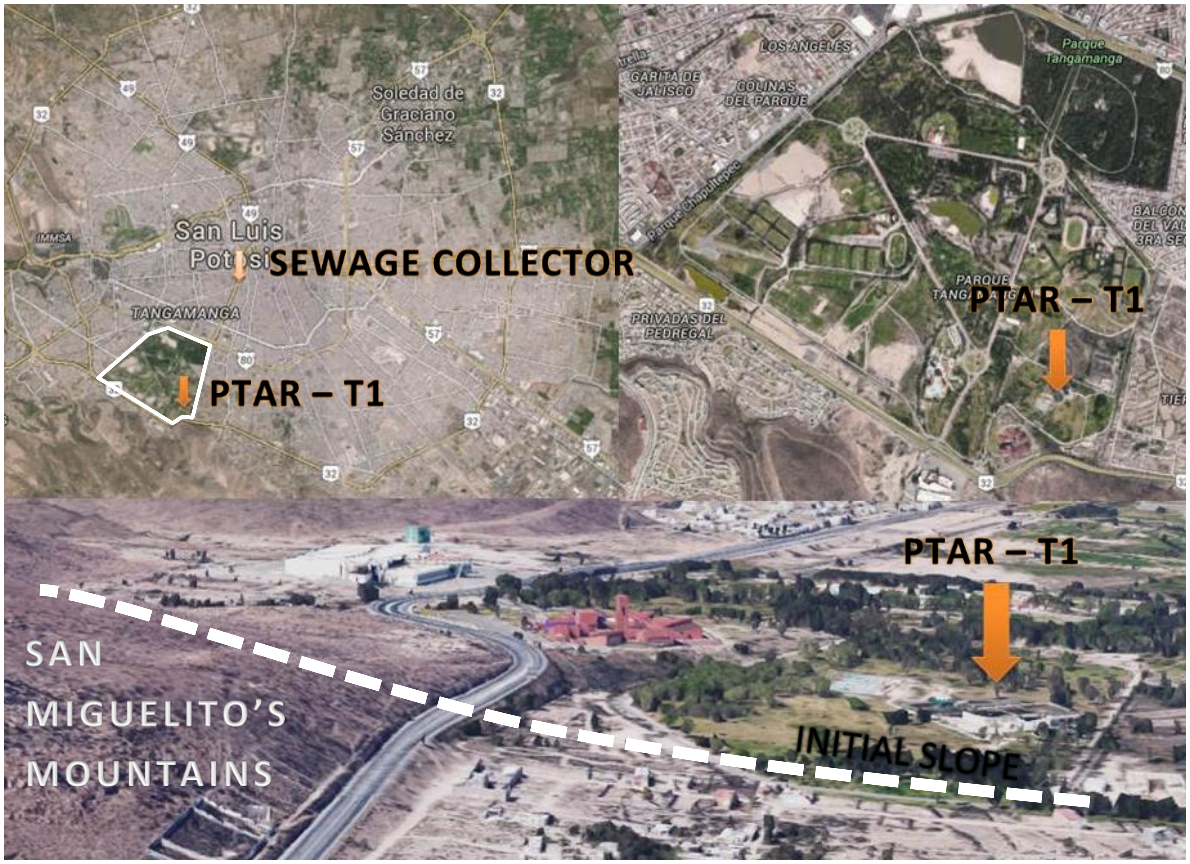

**Figure 13. PTAR – T1 WWTP location,** (Google/INEGI 2016)

The plant's design, called sequencing biologic reactors (SBR), is a type of activated sludge with all process performed in one tank. The T1 plant counts with two SBR tanks and four additional tanks for pre and post processes. The pumped influent arrives to the plant with 400 of COD, 200 of BOD and 21°C average to be treated with an efficiency of 96% of organic matter removal. In about 3 hours the water is treated and stay into the plant, in the storage tanks, about 11 more hours before to be pumped for irrigation. The surplus sludge (120 – 140 m$^3$/d) that cannot be conserved for latter inoculation of the incoming water is dried over dehydrating beds until reach about 85% of humidity; there after is sent to be confined by the local landfill (Dautan et al. 1998; STPS 2013; Olvera 2016a).

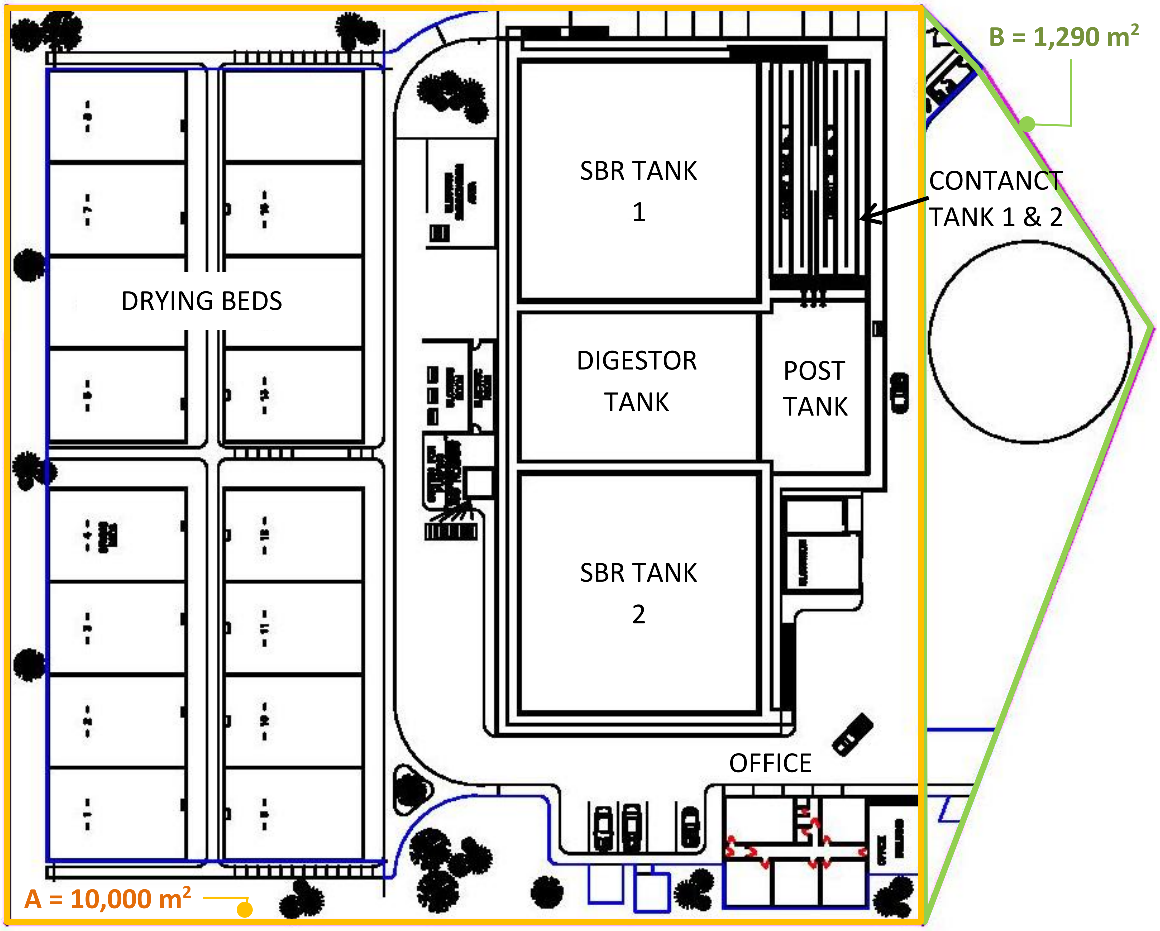

Figure 14. PTAR-T1 WWTP layout, (PROAGUA 2016)

The plant's area is about 11,293.6 $m^2$ and is divided in *two main areas*: the rectangular *shape A* which has a space of *10,000* $m^2$ and is fenced in its entire perimeter, and *shape B* with non-fenced *1,290* $m^2$. In the last ten years the average of treatment per month has been around the 259,903 $m^3$ with a power factor of 96.24%, depicting great efficiency. The amount of kWh consumed in one typical month is 254,331 with an energy requirement for treatment of 0.98 $kWh/m^3$ (see Olvera 2016a). For more information about energy plant's requirements please see next section.

## *Plant's load profile.*

The plant is connected to the national grid to a medium voltage distribution line (distribution lines in Mexico exist in 34.5 and 13.2 kV) with a transformer. Thereafter, the voltage is reduced to 460 V to supply the bigger blowers (aeration pumps) which work at 440 V; then reduced at 220 V to supply medium and small pumps; and finally to the 110 V required for lighting and small equipment (Olvera 2016a). The load each equipment represents is listed in the next table.

| **Plant's equipment load** | | | | | |
|---|---|---|---|---|---|
| **No.** | **Equipment** | **HP** | **kW eq.** | **Total (kW)** | **%** |
| *3* | *Blowers* | *110* | *82.06* | *246.18* | *36.47%* |
| 1 | Blowers | 75 | 55.95 | *55.95* | 8.29% |
| 2 | Blowers | 40 | 29.84 | *59.68* | 8.84% |
| 3 | Blowers | 7.5 | 5.595 | *16.785* | 2.49% |
| 3 | Blowers | 3 | 2.238 | *6.714* | 0.99% |
| 2 | Backup blowers | 7.5 | 5.595 | *11.19* | 1.66% |
| *4* | *Pumps* | *75* | *55.95* | *223.8* | *33.16%* |
| 1 | Pump | 25 | 18.65 | *18.65* | 2.76% |
| **Heavy equipment load** | | | | **638.949** | **94.66%** |
| 15 | Outside lighting | | 0.25 | *3.75* | 0.56% |
| Small and indoors equipment | | | | *32.30* | 4.79% |
| **Total load declared to CFE** | | | | **675** | **100%** |

**Table 15. Different loads in PTAR-T1 plant, own realization with information from** CONAGUA (2009) and Olvera (2016a)**.**

It could be seen in Table 15, aeration equipment represents near to 60% of the total load, while typical pumps represent just 36%. The rest of the load is attributed to lighting and the equipment used in offices and laboratories (Olvera 2016a). Due to the sequential process, not all the equipment can be used at the same time, therefore, the amount of energy demanded from the grid is lower than the peak load. Such demand depends on many factors, but the influent and its quality are the most important in this case. Normally, influent characteristics and quantity vary from month to month and year to year, therefore, the purple line in Figure 15 has no regular values and its changes vary drastically. Nevertheless, there is a very clear rise tendency in treatment that has slightly grown since the last 10 years.

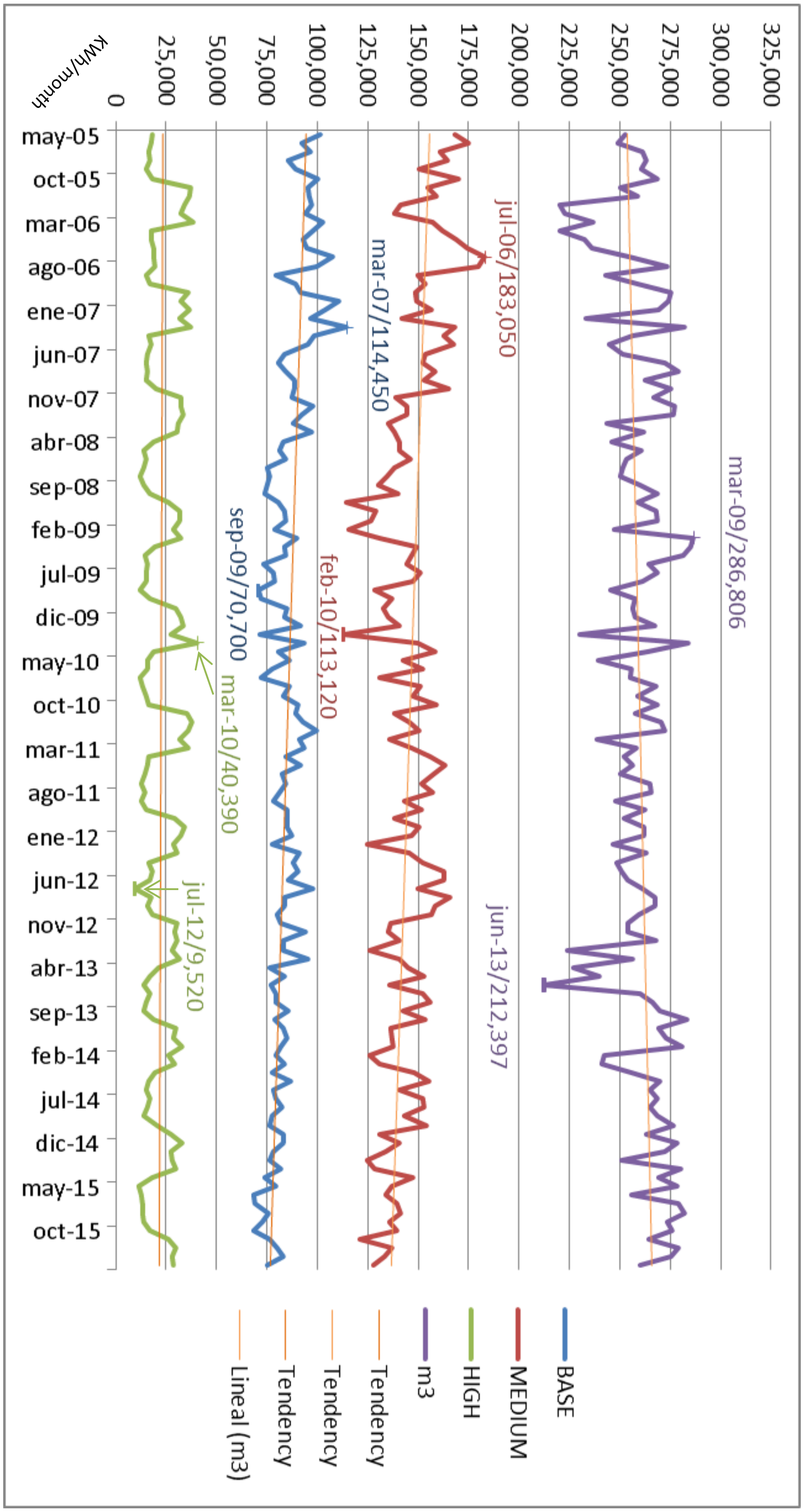

**Figure 15. Influent and energy record (kWh/m) in WWTP – T1, own realization with information from** Olvera (2016a)**.**

The tariff payed by the plant is the H-M one, which is a scheduled tariff with different platforms (base, medium and high) along the day. This explains why in Figure 15 there are 3 *consumption lines*: being the *medium* one the most consumed by the plant, seconded by the *basic* and finally the *highest*. In the figure, the three tariffs have a negative tendency in terms of usage; depicting efficiency and good management into the plant. To better understand this, Table 16 shows maximum, average and minimum monthly values to depict the plant's performance.

| **Treatment** | **M3/mo** | **Demand (BASE)** | **kWh/mo** |
|---|---|---|---|
| Max | 286,806 | Max | 114,450 |
| Avg | 259,001 | Avg | 84,632 |
| Min | 212,397 | Min | 68,320 |
| **Treatment efficiency** | **kWh/m3** | **Demand (MEDIUM)** | **kWh/mo** |
| Max | 1.26 | Max | 183,050 |
| Avg | 0.97 | Avg | 144,985 |
| Min | 0.80 | Min | 113,120 |
| **Power factor (PF)** | **%** | **Demand (HIGH)** | **kWh/mo** |
| Max | 97.71 | Max | 40,390 |
| Avg | 96.24 | Avg | 19,880 |
| Min | 93.45 | Min | 9,520 |

**Table 16. Plants overview, own realization with information from** Olvera (2016a)**.**

## Energy resources evaluation (pre-assessment)

Now having the basic information regarding the plant, the present section will start to evaluate the available resources based on the list of employable RE technologies over WWTPs, mentioned in chapter one. The methodology to evaluate them varies from case to case because the information source and methodology differ for each resource and technology. As any project, there present one has spatial limitations for technology implementation, limiting any infrastructure within the boundaries of the plant. Therefore, any element pertaining to the energy scheme cannot go beyond the limits into the green areas. Additionally, one side to the plant there are facilities of the forest national commission which has started to plant trees over the surrounding areas of the plant (see Figure 16). The assessment was made over five resources and technologies recommended in chapter 1, this, considering the location and plant characteristics. The result of such assessment says *two* of the five *technologies* are feasible for implementation:

*biogas* and *solar*, and them are going to be evaluated in further steps of in technical and economic terms (please see Table 17 and Annex 1 for more details about the pre-assessment).

Figure 16. Plant location with respect green areas (Google/INEGI 2016).

| Resource | Result of resource assessment | Feasible |
|---|---|---|
| Heat pumps | There is no need of cooling or heating processes due to the type of wastewater treatment. | No |
| **Biogas** | It was selected as average residual sludge of 130 m3/d, which has a theoretical methane generation of 45.46 m3/d with a power yield of 15,077 kWh/d. | **Yes** |
| Hydro | The potential energy to be harvest from a micro hydropower system is quite small (127.13 kWh/d), representing 1.5% of the energy used in a month. | No |
| Wind | Fairly possible to have turbulences because the plant is located into a green area, which is surrounded by many trees of different sizes. Power density by Vestas: 0 (W/m2) and by CFE 0 – 200 (W/m2) (INERE online tool). | No |
| **Solar** | Global irradiation per year exceed the national average (5 kWh/m2/d) 6.88 kWh/m2/d of global irradiation in inclined plane (18%) | **Yes** |

Table 17. Assessment of resources and technologies over the PTAR T1 in the Tangamanga park.

## Technical and economic feasibility evaluation

Technical and economic evaluation may differ between technologies because their respective characteristics and the tools to assess them are different in some extend. For the biogas option, the technical evaluation was made manually using excel spreadsheets, technology data and the biogas production obtained in the pre-assessment evaluation. On the other hand, the PV assessment was made by using a software (BlueSol Design) specialized in PV systems modelling with the intention to give more certainty about losses, equipment and meteorological conditions. For economics standings, the present work considers advisable to use firstly one of the pre-economic evaluation methods (payback period, IRR and WACC) in order to obtain economic references for the LCOE. For both technologies it was considered some general assumptions coming from the factors affecting economics and the policy regime the project is immerse. Next list shows such assumptions, making space for the following evaluations.

- The plant is interconnected to the grid: legislation allows renewable energy systems connectivity and for this case study, the power plant is considered to be connected as *exempt generator* with *isolated supply*.
- Inflation rate of 2.5% (BANXICO 2016b).
- No lending from financial institutions: it is assumed the municipality may reach means from the water state commission to invest into the project.
- The plant pertains to the municipality or a state entity.
- No depreciation or tax shield: the case study considers municipal WWTPs do not pay taxes.
- Use of grants and incomes coming from certificates.
- The starting year of the project is 2018: this, considering a procurement process and a construction phase during 2017. Thus, the new market should be working normally, especially for CECs.
- For simulation purposes into the plant, it was selected the year 2015 because tariffs and demand are already registered into the collected data and such data has real tendencies. Therefore, any simulation can be contrasted with such data with a bit more certainty.

### Technical evaluation

The purpose of this estimation is to obtain potential energy outputs coming from real life technologies, which can be evaluated in technical terms and in accordance to the current plant conditions (electricity needs and grid connection type). The importance to consider current technology is because commercial technology, its capacities and the compatibility with the plant's requirements may draw the project proposal into reality.

### *Biogas plant*

The biogas power plant projection is build up considering the previous calculation of potential biogas production (45.46 $m^3$/d) and is assumed to come from a bio-digester system processing 130 $m^3$ of surplus sludge per day. For such system it was possible to found available commercial technology options in Mexico, making easier costs calculation in the next evaluation step (economic) (MOPESA n.d.; Aqualimpia n.d.). The characteristics of the considered system and its generation ratios are shown in the next table.

| **Technical details** | | |
|---|---:|---|
| Aqualimpia biogas generator size (nominal) | 6 | kWp |
| Expected annual system degradation | 1 | % |
| Average biogas generation (bio-digester bag type) | 45.47 | m3/day |
| Generator fuel consumption (at full capacity) m3/h | 5.28 | m3/h |
| Average hours of generation | 8.61 | h/day |
| Average daily electricity generation | 51.67 | kWh/day |
| Average yearly output (based on initial efficiency) | 18,858.89 | kWh/yr |
| Average yearly output (with conversion losses of 5%) | 17,915.94 | kWh/yr |
| Expected lifetime of biogas system | 20 | yr |
| **Operating assumptions** | | |
| Uptime | 100 | % |
| Operating days per year | 365 | days/yr |
| Non-operating days per year | 0 | days/yr |

Table 18. Biogas plant and power generator specifications and yields.

The reason to select the 6 kWp micro generator from Aqualimpia is because its ratio of biogas consumption fits more less with the calculated biogas production and also it was the smallest generator found into the market. It is important to emphasize; the present work considers biogas storage to allocate electricity production during peak demand hours or whenever the system needs it. This, with the intention to avoid, as much as possible, high cost tariffs.

### *PV solar plant*

As mentioned before, PV solar sizing was developed with the assistance of a software and including available components to support the simulation. Considering the case study characteristics, it was decided to create a project mainly based on the available area into the plant and its energy demand. Hence, the first stage of this assessment was to determine such area.

Analyzing the plausible space, it was concluded areas as the drying beds[67], offices and the parking lot are able to hold a system with a cumulative area of 3,497 $m^2$ in total and 3,183 $m^2$, 194 $m^2$and 120 $m^2$ respectively (see Figure 14). The scenario consists in using such available area for a PV system what consists in: 1066 300 W PV modules arranged in 82 strings with 13 panels each, one inverter with a sizing factor of 105%, three MPPTs and protection switches in each string. Table 19 specifies all parameters considered into the PV system.

| **Technical details** | | |
|---|---:|---|
| System size (nominal) | 319.8 | kWp |
| Expected annual system degradation | 0.7 | % |
| Average solar global irradiation | 5.49 | kWh/$m^2$/day |
| Average solar direct irradiation | 3.77 | kWh/$m^2$/day |
| Average solar diffuse irradiation | 1.72 | kWh/$m^2$/day |
| Maximum DC voltage | 631.41 | V |
| Maximum DC current | 721.6 | A |
| Maximum voltage MPPT | 511.81 | V |
| Maximum current MPPT | 371.43 | A |
| Shading loss | 0 | % |
| Conversion loss | 2.6 | % |
| Global loss | 12.89 | % |
| Average daily electricity generation | 1,613.94 | kWh/day |
| Average yearly output (based on initial efficiency) | 589,086.67 | kWh/yr |
| Expected lifetime of PV system | 20 | years |
| Minimum system temp. | 8 | °C |
| Maximum system temp. | 63 | °C |
| Number of strings | 82 | - |
| Number of panels | 1066 | - |
| Modules area | 2068.04 | m2 |
| **Operating assumptions** | | |
| Uptime | 100 | % |
| Operating days per year | 365 | days/yr |
| Non-operating days per year | 0 | days/yr |

Table 19. Photovoltaic plant specifications and yields.

The tariff structure contracted by the plant has prices platforms and schedules which divide the day in three parts. As know, solar energy is intermittent and in this case cannot matches all periods of the H-M tariff. Therefore, it has decided to include one scenario that includes a battery

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[67] The drying beds' area is considered just in the case a compost project is put online, otherwise, the PV project cannot be implemented fully.

system to allow the PV scheme to allocate electricity at any time of the day but particularly during peak time hours. Such storage system considers to accumulate 41% of the electricity generated in one day in silica gel batteries to try to cover completely peak time costs (Prat Viñas n.d.; CS POWER 2016). Please see in Table 20 all additional parameters considered for such scenario.

| **Technical details** | | |
|---|---|---|
| Battery losses - 5% (considering just 41% of energy going to the battery system) | 2.07 | % |
| Lifetime considering 937 cycles @ 80% DOD | 28 | yr |
| Expected lifetime of biogas system | 20 | yr |
| Battery Depth of Discharge | 80 | % |
| Nominal voltage | 12 | V |
| Battery capacity | 300 | Ah |
| **Operating assumptions** | | |
| Battery system size | 667 | kWp |
| Battery system capacity | 69,479 | Ah |
| Number of batteries | 232 | - |
| Number of batteries in series | 39 | - |
| Number parallel | 6 | - |
| Non-operating days per year | 33.17 | days/yr |

Table 20. Battery system specifications.

## Economic assessment

As mentioned before, it was considered advisable to perform a pre-economic evaluation of both technologies to give a first pace towards the levelized cost calculation. The methodology employed as pre-economic evaluation was taken from FSF&M (2014) and was merged with the factors affecting economics by Nelson (2011). The resultant is a spreadsheet that analyses general assumptions (technical, policy and economic) in a net present value function and estimating the IRR, payback period and cash flows of the project. Then, the internal rate of return of each technology is taken as a discount factor for its LCOE calculation. Despite the accuracy of the LCOE calculation, it was decided to simulate possible savings generated from a power plant in a real life demand situation because the T1 plant is under a scheduled tariff with variable prices along the day. To make this possible, a model was created to compare consumption with or without the power scheme along one ideal year. The selected year was 2015 and the designed function discounts from real demand and tariffs the kWh the plants may produce. Therefore, each plant was analyzed in terms of energy generation and the part of the day such generation might be allocated; this, considering the different timetable tariffs platforms[68]. Next sections explain in detail all particular assumptions taken for each case and scenarios.

### *Biogas plant*

The biogas plant has been already explained in technical terms and its specifications were fed into the economic models. The assumed costs were calculated considering the already mentioned technologies, their technical datasheet maintenance recommendations and some international institutions costs reports (IRENA 2015; WEC 2013; NREL 2016; Aqualimpia n.d.; MOPESA n.d.). Another assumptions, as contingencies or the replacement percentage for example, were guessed high because detailed information was scarce and therefore such costs were raised to protect the project. Table 21 shows more of the economic assumptions and results.

| **Economic assumptions and details** | | |
|---|---|---|
| Costs | | |
| Capital costs of biogas power systems in OECD countries (2011 average costs) | 3,924.24 | €/kWp |
| Contingencies | 10.0 | % |
| Development costs | 25 | % |
| **Total initial investment** | **31,786.36** | **€** |
| Total initial investment/kWp | 5,297.72 | €/kWp |
| Replacement capex: Amount as % of initial investment | 10.0 | % |
| **Replacement capex in EUR** | **3,179.64** | **€** |
| To be replaced in year | 10 | yr |
| Maintenance costs (% of initial investment) | 0.8 | % |
| Maintenance costs (in EUR) | 254 | €/yr |
| Revenues | | |
| Expected revenues in yr 1 (calculated reference retail price) | 6.43 | € cent/kWh |
| Yearly change | 2 | % |
| Starting year | 1 | yr |
| Clean Energy Certificates price | 22.2 | €/MWh |
| Financing structure | | |
| Grants (50% considering the Water Operators Modernization Programme) | 50 | % |
| Debt | 0 | % |
| Equity (compulsory to achieve the grant) | 50 | % |

Table 21. Economic assumptions and details.

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[68] The south region timetable is divided in two periods along the year: from the first Sunday of April to the Saturday previous to the last Sunday of October (Summer part) and from the last Sunday of October to the Saturday previous to the first Sunday of April (Winter part) (CFE 2016).

The calculated IRR turned out in **5.59%**, which seems good to be applied in the next economic evaluation step. One advantage in this particular technology and resource is, water legislation grants up to 50% biogas projects and for this project is considered to be achieved. This represents a positive income of 15,832 EUR at the beginning of the venture, increasing the IRR from -1.4% (without the grant) to the resultant 5.59%. The payback period is also benefited from the grant and gets positive in the year 13. The cumulative value at the final of the project is 11,281 EUR (see Figure 17).

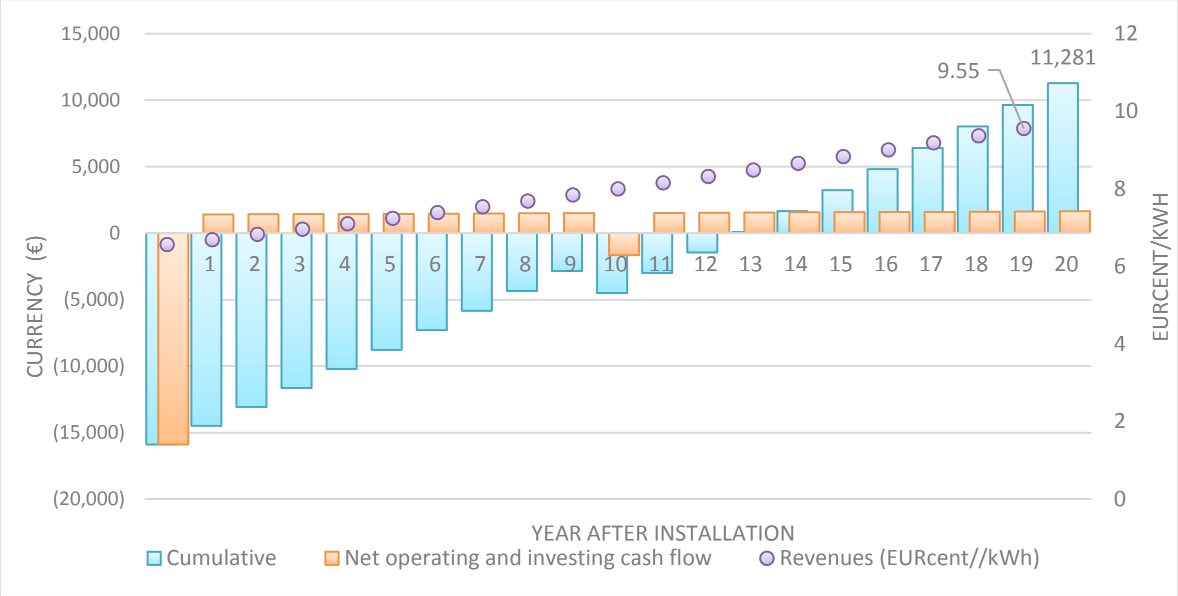

Figure 17. Biogas power generator cash flows.

The LCOE in this case has been split in two scenarios: one, considering a governmental grant and two, without it. The reason of such projection is because the levelizing methodology allows to obtain the cost of electricity from the same system but with different capital structure and, as a result of a comparison, it is possible to obtain the weight of policy support. In this regard, the first scenario does not reach the governmental support and its LCOE is *11 EUR cent/kWh*, while scenario two, which achieves the total support, has a LCOE of *6.4 EUR cent/kWh*. Taking this into account, it could be said the policy support has a value of *5 EUR cent/kWh.* If both costs are compared with 2015 CFE tariff prices, the first scenario exceeds the three tariff platforms, leaving the project without any chance to be implemented; while the second achieves a lower cost in comparison to the higher tariff and gets close to the medium one. This reflects economic suitability of the biogas project in some extend. However, due to the scheduled tariff system, the comparison between retail prices and levelized costs seems to be short in revealing economic suitability in a variable cost situation. This, because demand happens during all day and electricity generation from this specific project does not. To solve this, it was necessary to integrate biogas electric generation and its probable allocation within the real demand of the plant. The reasoning to allocate it was: to firstly assign generation during peak time demand, displacing high prices, and then backwards until reach the less expensive tariff and withdrawing all the possible generating power. The possible savings Figure 18 shows are rather small in comparison to the whole demand in a year. The 17,916 kWh the biogas power plant can generate represent less than 1% of the total demand and the allocation of electricity generation within the tariffs just account a positive cash flow of 2,009 €; this, despite earnings from CECs are also included into the cash flow.

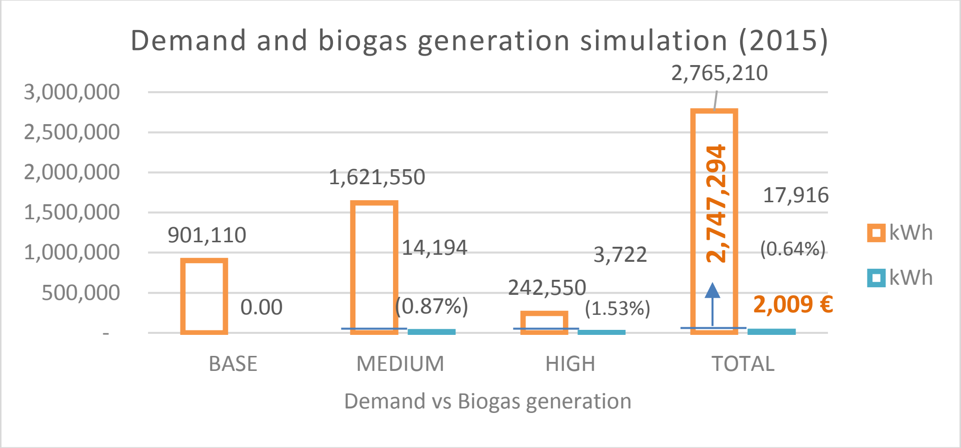

Figure 18. Biogas system online simulation and savings.

### *PV solar plant*

The PV plant, as well as the biogas one, has been explained in technical terms in the past sections and its costs were designated taking into account the selected technology but particularly based on reports costs ranges (IRENA 2015; WEC 2013; NREL 2016; IRENA 2012). The two scenarios for the PV plant consider the same available area and technology, with the difference the second scenario includes a battery system with all its technical parameters and losses. The first scenario considers to allocate its full generation under the medium tariff because the PV generation matches such schedule (06:00 till 20:00 hours). The second scenario was thought to displace, as much as possible, the peak demand tariff and the maximum power factor demand (MPFD) because they constitute the most expensive part of the plant's bill. The maximum power factor demand is a methodology employed by CFE to bill the capacity demanded from the electricity matrix and the merit order costs (CFE 2016). This factor into the bill represents about 33% of costs and its algorithm always give preference to the peak time measurements[69]. Therefore, a battery system trying to cut down such costs makes sense for this work. All mentioned components lifetimes were mixed to obtain the lifespan of the project, which is expected to be 25 years. The only replacement considered in this period is the inverter, which will be replaced until the year 20 (ERDM 2013; ADVANCE ENERGY n.d.). For more economic assumptions and results of both scenarios, please continue through the next sections.

### Scenario 1

One difference that can be noticed between the biogas power system and the PV one is, there is no access to any grant for PV systems, therefore it is assumed the entire project will rely over equity means. But regardless of this, the internal rate of return of the PV project scored higher in comparison with biogas one, achieving **7.09** percent. The payback period also is improved, achieving positive cash flows in the year 12 and a final cumulative value of 698,713 € in year 25 (please, see Figure 19).

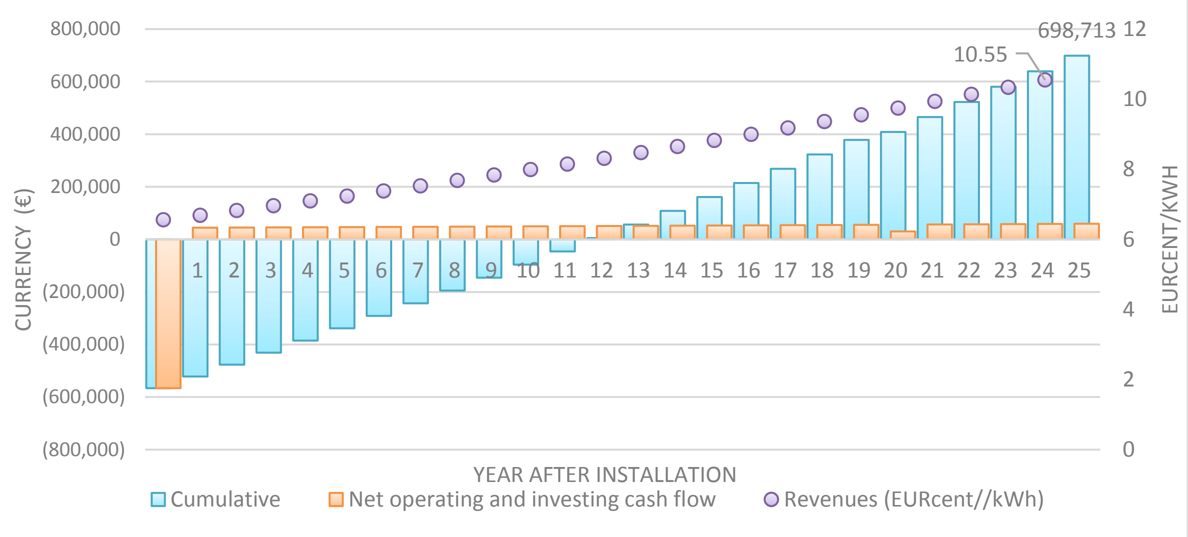

Figure 19. PV power plant cash flows.

Using this rate as discount factor for the LCOE results a good PV electricity price the system alone (*5 EUR cent/kWh*), which is lower than the calculated reference retail price (*6.43 EUR cent/kWh*) and in real terms gets under the peak time tariff (average *9.16 EUR cent/kWh*) and in the middle of the maximum (*5.5 EUR cent/kWh*) and average (*4.35 EUR cent/kWh*) medium tariff prices of the

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[69] The measurement of the maximum power factor demand is made each 15 minutes along the month and the selected measurement to be reflected into the bill is always the major registered during the period (CFE 2016).

reference year. The corresponding assumptions to calculate the IRR and the LCOE for this scenario are listed in the next table.

| **Economic assumptions and details** | | |
|---|---|---|
| Costs | | |
| Capital costs for PV system (USA 2012 costs) | 1,609.38 | €/kWp |
| Contingencies | 10.0 | % |
| Bidirectional meter cost (CFE) | 90.91 | € |
| Total initial investment | 566,146 | € |
| Total initial investment/kWp | 1,770.31 | €/kWp |
| Replacement capex: Amount as % of initial investment | 5 | % |
| Replacement capex in EUR | 25,733.91 | € |
| To be replaced in year | 20 | yr |
| Maintenance costs (% of initial investment) | 1.3 | % |
| Maintenance costs (in EUR) | 7,268 | € |
| Revenues | | |
| Expected revenues in yr 1 (calculated reference retail price) | 6.43 | € cent/kWh |
| Yearly change | 2 | % |
| Starting year | 1 | yr |
| Clean Energy Certificates price | 22.2 | €/MWh |
| Financing structure | | |
| Grants | 0 | % |
| Debt | 0 | % |
| Equity (compulsory to achieve the grant) | 100 | % |

Table 22. Scenario 1 economic assumptions and details.

As mentioned before, the allocation of the PV daily generation of this scenario just can be during the medium tariff timetable, dropping the cost-effectiveness of the project because the high tariff and its respective maximum power factor demand cannot be reduced at all. Despite this, the displacement of kWh and kW in the medium tariff may have a positive influence because the first scenario's LCOE is between the range of such retail prices. In this scenario the PV system reduces demand from 2.76 to 2.17 GWh in one year, representing 21% less electricity demanded in total and 36% less from the medium tariff timetable. Savings and incomes accounts about 26,123 € at the final of the representative year, please see figure below.

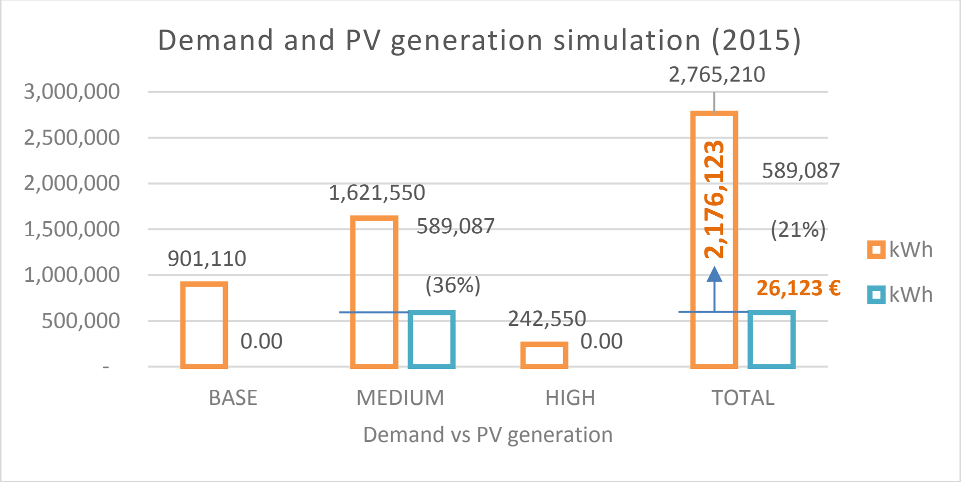

Figure 20. PV online system simulation and savings.

### Scenario 2

This scenario includes a battery system which allows to allocate generation not only in the medium tariff schedule, as the first scenario does, but also during the peak time demand. Savings are expected to increase because expensive electricity costs during peak time are projected to fall. Nevertheless, capital costs are also anticipated to rise. Regarding this, the added storage represents 45% more cost in comparison with the previous scenario and its IRR also suffer a cutback from 7.09 to **3.6%**. Table 23 shows the economic parameters employed to calculate the scenario.

| **Economic assumptions and details** | | |
|---|---|---|
| Costs | | |
| Capital costs of PV system (USA 2012 costs) | 2,307.57 | €/kWp |
| Contingencies | 10.0 | % |
| Bidirectional meter cost (CFE) | 90.91 | € |
| Cost per battery | 962.42 | € |
| Battery system cost | 223,282 | € |
| Total initial investment | 811,757 | € |
| Total initial investment/kWp | 2,538.33 | €/kWp |
| Replacement capex: Amount as % of initial investment | 5 | % |
| Replacement capex in EUR | 25,733.91 | € |
| To be replaced in year | 20 | yr |
| Maintenance costs (% of initial investment) | 0.9 | % |
| Maintenance costs (in EUR) | 7,268 | € |

| Revenues | | |
|---|---|---|
| Expected revenues (yr 1) | 6.43 | € cent/kWh |
| Yearly change | 2 | % |
| Starting year | 1 | yr |
| Clean Energy Certificates price | 22.2 | €/MWh |
| **Financing structure** | | |
| Grants | 0 | % |
| Debt | 0 | % |
| Equity (compulsory to achieve the grant) | 100 | % |

Table 23. Scenario 2 economic assumptions and details.

Looking at the cash flows in Figure 21, it can be seen the battery system also increase the payback period four years more until reach year 17. Savings per kWh reach the *10.55 EUR cent* at year 25 and have a cumulative positive value of 453,103 €; 245,610 € less than scenario 1. The levelized cost of electricity of this scenario accounts *7.38 EUR cent/kWh*, which is under the range of the higher tariff (*8.42* to *9.99 EUR cent/kWh*) but over the medium one (*5.53* to *3.47 EUR cent/kWh*). Despite scenario 2 economic results are lower in the common economic thinking with respect scenario 1, is considered its performance is positive; this, because peak time costs are expected to be reduced with the allocation of energy from the battery. This can be seen in Figure 22 in which the positive cash flows are compared with the total demand of one year.

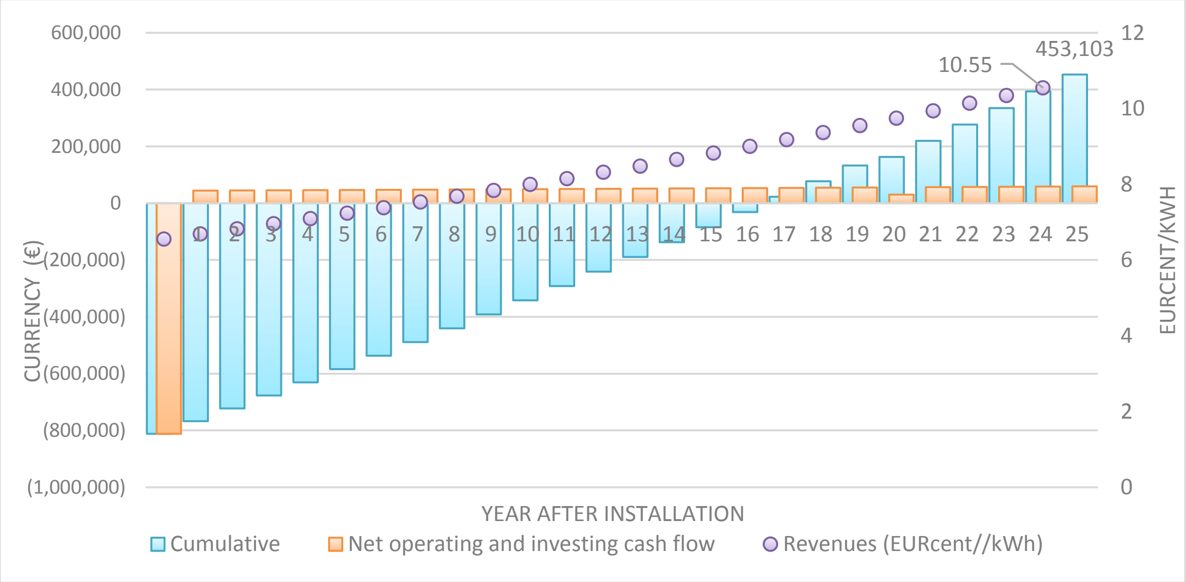

Figure 21. PV + battery power plant cash flows.

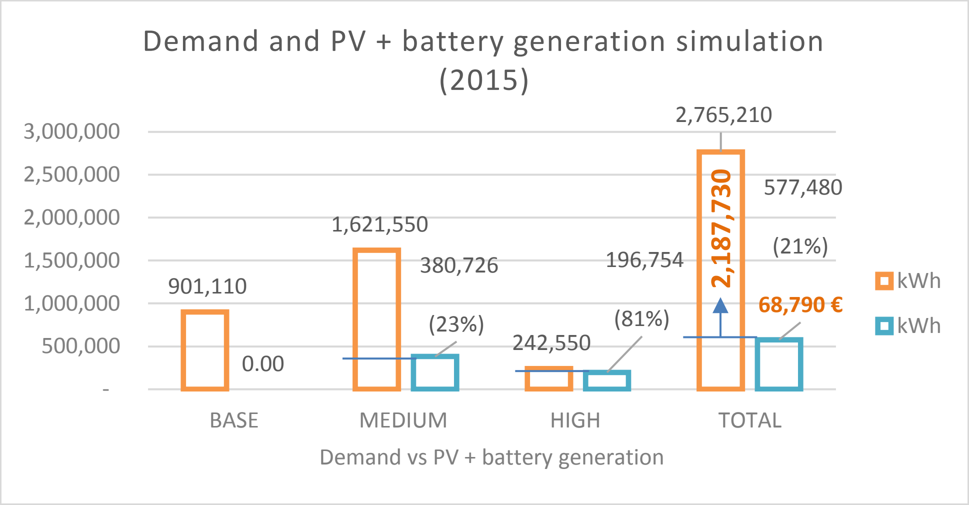

Figure 22. PV + battery online system simulation and savings.

In the figure above, it can be seen the total amount of kWh/yr diminished slightly in comparison to the baseline PV system due to the battery loss effect. This has economic impacts but can be ignored because the battery system has a greater positive outcome, increasing savings by 2.6 times (68,790 €/yr) compared to the calculated ones of scenario 1 (26,123 €/yr). This result becomes possible because the battery allocates generation during the peak time demand, displacing 81% of it throughout the schedule by reducing about 197 MWh (from 242,550 to 45,796 kWh). The rest of electricity generated by the PV system is allocated in the medium tariff timetable, reducing 23% the electricity coming from the grid (from 1.62 to 1.24 GWh/yr). In total, the PV + battery system decrease demand about 21%, from 2.76 to 2.18 GWh/yr in the simulated year.

## Discussion

The results given by this chapter reveal technical and economic suitability of renewables over wastewater treatment plants is possible in Mexico. From the fifth possible technologies to be implemented, two were selected as suitable in technical and operative terms, as Chae & Kang (2013) do in their study. Both were found to be quite plausible to be constructed with good efficiency factors, but just one can be considered representative as a supporting strategy towards energy independence. PV technologies does not use any residual energy coming from the WWTP, but despite this, it is the only one that can help to reach such independence. This does not mean biogas technologies recovering residual energy from WWTPs have less technical applicability. On the contrary, these technologies applied to the right wastewater depollution process may reach partial or full energy independence of a plant, as Nowak et al. (2015) claim. The issue that becomes biogas technologies in this case study unviable is the low energy output that can be extracted from the residual sludge of the plant, accounting less than 1% of the demanded electricity of one year. A positive fact found into the present research is, biogas technologies applied to WWTPs are well economically supported by the current water policy and this can be used by water operators and plants owners to implement such technology and get benefits from it. Such supports changed completely the economic suitability of the evaluated biogas project, increasing its IRR from a negative value to a positive one.

This may lead to the next question. How big biogas technology can be if it is applied to WWTPs in Mexico? In an overoptimistic scenario in which 100% of wastewater is collected and treated, near to 68% of $CH_4$ now released could be captured. This represents, according own calculations, 1,643 GWh per year of electric power. If that is considered to be connected to the grid, the new infrastructure could have an annual value of: 36.47 million euros for CECs and 65.46 million euros for the electricity sales (considering 60% of the produced energy is sold directly to CFE with a marginal price of 66.4 EUR/MWh), being in total 101.93 million euros per year. The present research considers this as an ideal opportunity because unconstructed infrastructure is already planned to be done at some point, and the CAPEX of both technologies (treatment and power) can be merged in order to reduce their weight of capital. Of course, more research is needed to better calculate the economic potential of biogas technology into the sector, however, seems to be promising.

Coming back to the PV case, the present work could not demonstrate the real weight current energy policies have over this specific technology. This, because the project conditions did not allow to use all benefits from the current energy legislation in Mexico. For example, the tax shield or accelerated depreciation could not be used in this evaluation because the plant pertains to a governmental institution that do not pay taxes. Therefore, such benefit could not be applied. The only benefit assumed to be provided by a current policy, was the income clean energy certificates represent.

The economic analysis performed by this research uses some of the most recognized methodologies to assess economic suitability of RE projects, standing in the higher place the LCOE. All applied methodologies (IRR, payback period and LCOE) gave positive results to all evaluated projects, therefore, all of them are economically suitable to be implemented from a simple economic appraisal. The present work found these economic evaluation tools cannot be taken as absolute results. They must be interpreted and put into the real perspective of the evaluated project; this, considering the majority of factors that can affect operative and economics performances. The schedule characteristic of the H-M tariff represented a challenge for the economic evaluation of this work because power generation and demand does not match all the time. The only way to cope with that was to firstly understand the rules of electricity billing and from that construct a strategy and the way to evaluate the economic performance of each project proposal. This has to be considered at the moment of reading conclusions because probably the best performer in the methodologies of assessment may not be classified as the best option for the case study.

## Conclusions

Once gathered all results from the present research work, it can be said the implementation of renewables over wastewater treatment plants in Mexico is plausible, but depends heavily on the specific conditions of the selected plant. The pre-assessment ran by this analysis showed not all renewables are applicable to the same project, but at least one or two have potential to be implemented in such type of plants. The leverage effect of policies over renewable energy projects can be enormous and may change the face of the economic viability of a project. In this case study, the biogas proposal was highly benefited for a grant, becoming the project from non-admissible to very plausible. Additionally to the policy support effect, this work found market conditions might exert a heavy influence over the entire situation and future of a project, particularly when such venture aims to participate in trading activities and interact with other actors into the market. Therefore, the position in which the project will be performing into the market must be taken meticulously. From the five technologies recognized as applicable to WWTPs just two pass through the evaluation process: biogas and photovoltaic systems. Both were calculated as a power generation scheme of the selected WWTP and then evaluated economically. The biogas project is considered too small and ignorable for its implementation into the plant because the energy output does not represent any advantage towards energy and economic independence; this, regardless the good results obtained in the IRR and the LCOE calculations. In the PV proposal, both scenarios got positive performances under the economic evaluation methods, but the first scenario obtained better results in the IRR and the LCOE modeling in comparison to the second. In spite of this, the present work considers scenario two as a better investment option because in real time conditions such scenario may reduce expenses more effectively than the first. This was observed at the moment to simulate the power schemes' performance into the plant during one year. The PV plus battery scheme gave the plant the ability to allocate electricity at the moment of higher prices, cutting back more costs than a PV scheme without storage. The advantage storage systems may represent to exempt generators is quite good, especially for those registered as basic service users using medium tension tariffs. Such systems allow to cut back demand costs at the moment the plant requires it and also help to generate extra income by selling CECs. The extra profit can be increased if other related products (controlled demand and electricity surplus selling), not explored in this work, are sold into the market or to CFE. This demonstrate that despite the extra cost storage systems can represent into the CAPEX of a project the returns are quite attractive if the project is set in the right position into the market. In other words, renewables can be considered suitable for implementation into WWTPs in technical and economic terms and the current electricity and water policy structure in Mexico helps to achieve such suitability. This statement is made considering particularities of wastewater treatment and energy policies and possibly an optimistic point of view, however, it is important to remember policy and its implementation not always go through the same path and the implementation gap is a latent possibility in markets and structures which are still under formation. To avoid this, the effort may come from many parts and actors, but governmental ones have the most important task by the moment, which is to shield the upcoming market against corruption, political usage and other misconceptions, into a sector that is used to have them; otherwise, no reform or law will prosper in its implementation independently they are good or not.

# Annex 1

## Assumptions for anaerobic digestion in Table 6 (chapter 1)

For the case of anaerobic digestion, it was considered what some authors said and the current situation of the sector in Mexico. For example, Nolasco (2010) reported anaerobic processes have an energy demand near to 7% (0.1134 kWh/m$^3$) of activated sludge values (considering 1.89 kWh/m$^3$) when no heating is involved; and on the contrary, anaerobic demand values can reach the activated sludge ones when heating is applied. For the case of IMHOFF and septic tank it was decided to be ok the values mentioned before, but for UASB technologies it was decided be better to make an equivalent. Márquez & Martinez (2011) state UASB technologies with heating systems might consume about 11.66 kWh/m$^3$ when temperature is risen from 20° to 30° and also it was found maximum anaerobic digestion is when temperature is maintained at 22° (US DoE 2013). Now, considering Mexico has an average temperature during the year of 21.9° (SMN/CNA 2013) and sometimes some heating could be need; it was considered a temperature rising would be up to 3° instead the 8° to reach the 30° recommended by Márquez & Martinez. This result in 1.8 kWh/m$^3$ to make it possible. Combined and physicochemical technologies were represented with average values found in literature (PAHO 1992; Plappally & Lienhard V 2012). The technology named “others” was not defined by CONAGUA, therefore, it was assumed those other technologies represent tertiary treatments and variations of the other technologies. This was calculated considering the highest value of tertiary treatments (10.55 kWh/m$^3$) and an average of the rest of the technologies.

## Policy assessment methodology (chapter 2)

The way results are compound is by ‘*two components’*: the ‘*digit*’ (0.0) is the value level that express the component`s situation in relation to the optimum and desirable output. For example, if a policy has started recently to be operative is usual its goal, at the first stages, appears unreached and with a small progress, therefore, would be common that recent enacted policies have lower levels of achievements than well stablished ones. Another factor that may influence policy achievements is the complexity of its task. For instance, it would be easier to achieve a goal in which resource allocation is the target rather than make those means to reduce poverty in some socio-economic sector. In this way the present work tries to evaluate the different components regarding policy components and the structure; the ‘*arrow*’ works differently, but also describes the situation of a component but with a projection in to the near future. This, considering the current situation expressed in the digit but considering the influence a policy or a group of them may have over the component. Coming back to the policy example in its first stage, imagine one policy with a concrete goal, timing and resources. The most probable result is such policy has a positive tendency in the near future if all means are used correctly. Of course, there are other factors that may influence its success. However, is more probable a loose policy with no specified targets, no clear responsible or parameters to measure it fails in its purposes rather the one is well structured. This is more less what described by Barbosa et al. (2016) as a "policy implementation gap" and what SENER (2013b) describes as weaknesses of past programmes. The leverage effect of a policy step is the cluster impulse of policies over the sector and describes if the sector is ready or not in that level of knowledge and development. The calculation is different despite has the same constituents (digit and arrow). The leverage digit is the average of all components' results constituting a step and the arrow is a subtraction firstly between the current result and its optimum (always 2.0) that gives a resultant (positive, negative or neutral depending on the arrow direction). The resultants with the same tendency (arrow direction) are added together to conform a tendency group, then the resultants groups are compared amongst them and the final resultant is the final tendency[70].

## Resources and technology pre-assessment process

### Heat pumps

Regarding heatpumps and the need to cool or heat the administration of the plant said, there is no need for cooling or heating wastewater during its decontamination process because treatment is aerobic. Space heating or cooling are not considering into this assesment because the offices are rather small and there is no infrestructure to receive any output coming from a heatpump (Olvera 2016a). Therefore, heaqtpumps do not match energy needs of the selected WWTP and they are not considered for next technical and economic assessments.

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[70] If there is only one group, automatically the tendency will be that; if there are two groups the tendency will be the subtraction result between them and if the result is cero automatically the tendency will be neutral; if there are three groups firstly the two bigger are subtracted and then the result is compared to the third in size and the resultant from that will be the tendency of the policy step.

## Biogas

For biogas generation it was used the mathology and values employed by Blanco Jara (2014) to calculate the the theoretical energy contained in methane produced by sludge residue of an aerobic digester in standar conditions at 35°C, which is expresed in the next formula.

$$V_{CH_4} = (0.40)\left[(S_0 - S)(Q)\left(\frac{1kg}{10^3g}\right) - 1.42P_x\right]^{(71)} \qquad \textbf{(3.10)}$$

The set temperature was considered optimum and to be achievable despite the average yearly temperature in the municipality of San Luis Potosi which is 16.8°C; this, because it is considered a residual thermal energy coming from a generator to help to maintain the ideal temperature (SLP Municipality n.d.; Blanco Jara 2014; Chen & Chen 2013). Considering the plant generates between 120 and 140 m$^3$/d, the formula was adjusted in order to represent such values of sludge. In this regard, it was considered advisable to take a representative number of the range, resulting 130 m$^3$/d the one with a theoretical methane generation of 45.46 m$^3$/d and with a power yield of 15,077 kWh/d; this, considering a calorific value and density of methane of 13.88 kWh/kg and 1.86 kg/m$^3$ respectively. Thereafter, the power yield was converted into electric power with a 65% of efficiency factor and translated into monthly values. The result was compared with the monthly demand of the WWTP to calculate possible savings in electricity, giving biogas generation and conversion to electricity could represent up to 15% of the total electricity demand. Therefore, biogas resources and technology are considered suitable for energy generation in the case study (see Annex 2-spreadsheet for more information about calculations).

## Hydro

Hydro potential was calculated using the plant's treatment capacity of 12,960 m$^3$/d (0.15 m$^3$/s) as a flow and the total head of 6 m, giving a potential energy of 8.82 kW and an electrical generation potential of 127.13 kWh/d or 3,814 kWh/m with a conversion factor of the generator of 60% because it was considered to use a pump in reverse as a generator with a relative discharge of 70% (Power et al. 2014). The potential energy to be harvest from a micro hydropower system is quite small (representing 1.5% of the energy used in a month) and could not be considered because the post tank, where the water is going after treatment, is directly connected to an irrigation pump, excluding any chance to use a pump in reverse as a generator. This situation exists because space

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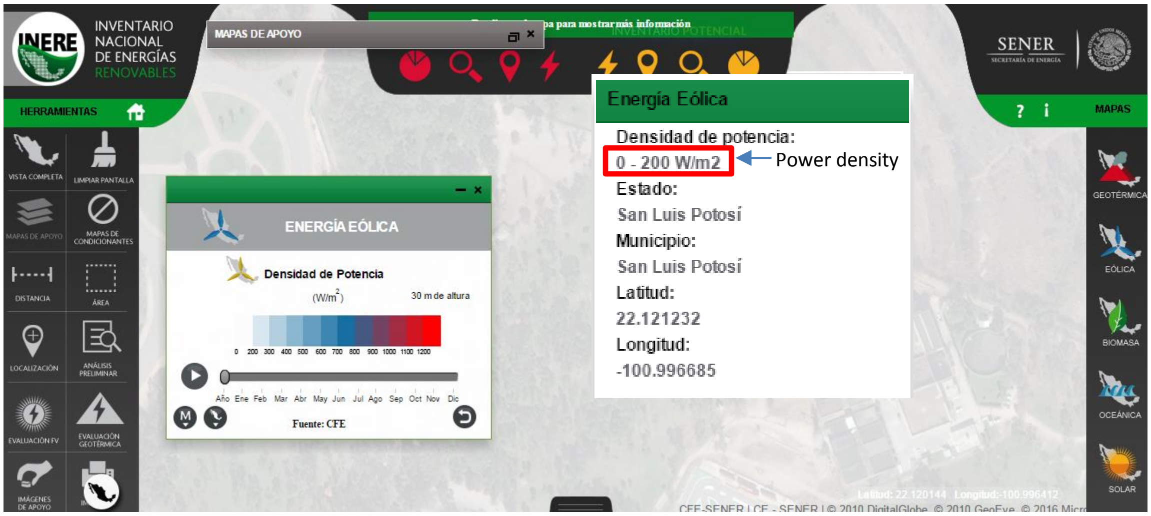
[71] $V_{CH4}$: methane generation in m$^3$; 0.40: conversion factor of methane at 35°C; $S_0$: inflow suspended solids; S: outflow suspended solids considering the digestion efficiency of a plant, and; $P_x$: cellular tissue mass factor (Blanco Jara 2014).

issues, therefore a different system or a modification becomes difficult and chaotic in a such compact system.

## Wind

In the case of wind, the results are not positive for the technology. On the one hand, the area is full of rough surfaces and obstacles that may diminish wind velocity. This, because the plant is located into a green area, which is surrounded by many trees of different sizes and therefore it is fairly possible to have non-predictable changes in wind speed and direction (turbulences). Mathew (2007) mentions such turbulences can reduce the power available in wind and also may enact fatigue over the turbines and therefore smooth surfaces always represent better wind spots. Besides the already existing obstacles (trees) and the turbulences they may create, it can be seen in Figure 16 there are adjacent areas being afforested, creating potential turbulence spots. It is important to consider this because the new forested areas may grow in size and height and other non -forested ones can be planted in the future, especially because the plant is beside the forest national commission's greenhouse. On the other hand, the survey made over the area does not give any encouraging result about the wind potential. For that, it was used the interactive online national renewable energy inventory tool (INERE), which allow to know in different heights and locations the wind characteristics and energy generation potential (see Figure 23).



Energía Eólica
Densidad de potencia:
0 - 200 W/m2
Estado:
San Luis Potosí
Municipio:
San Luis Potosí
Latitud:
22.121232
Longitud:
-100.996685

Figure 23. INERE national inventory over PTAR 1 (CFE-SENER 2010)

The online tool allows to select between two methodologies of measurement: one developed by CFE and the other by VESTAS. In both cases it was assumed the best height to the present project was the lowest; this, because were considered small turbines. The next table shows the mean velocity and the possible power generation in the selected heights and studies.

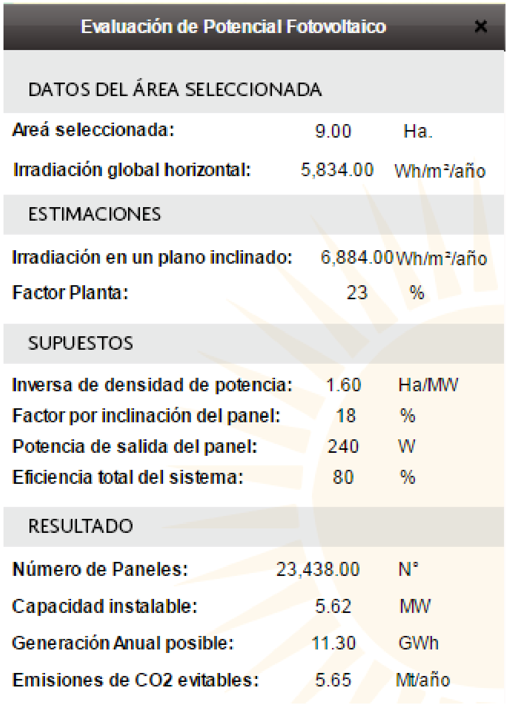
| Methodology | Height (m) | Mean velocity (m/s) | Power (W/m2) |
|---|---|---|---|
| **Vestas** | 50 | 5.5 | 0 |
| **CFE** | 50 | 5.5 - 6 | 0 - 200 |
| **CFE** | 30 | 5.5 | 0 - 200 |

**Table 24. Wind measurements, own realization with information from** (CFE-SENER 2010)**.**

Both studies show at the location of the plant the probable electricity generation is ignorable and almost zero. This in addition to the roughness of the terrain suggest the potential electricity generation cannot be considered for implementation of wind energy technologies.

### Solar

In terms of resources, Mexico is considered a good place to harvest because is located into the "solar belt" and has a national average over 5 kWh/m$^2$/d, which is considered very good. Additionally to this, photovoltaic manufacturing industry in Mexico is well developed and therefore it is considered one of the five best spots in the globe to invest in this technology (SE 2014). This potential makes technically feasible PV projects in all Mexican territory by default, however, it was necessary to examine the case study's spot. For that, it was employed again the online tool of INERE, giving the spot has a global irradiation per annum between 5.5 and 6 kWh/m$^2$/d, which surpass the national average. Also, the temperature of the spot is quite good for photovoltaic cells, being the annual average temperature between 16 to 18°C and the maximum between 24 and 26°C. Using the same tool, it was assessed the feasibility of PV systems in the area, resulting the irradiation in inclined plane (18% with respect the ground) and with a plant's factor of 23% is 6.88 kWh/m$^2$/d, which is quite high (CFE-SENER 2010). It is important to mention the PV assessment developed by the INERE online tool considers a minimum surface of 7 ha, which exceeds hugely the project boundaries. Thus, the values cannot be assumed as valid for the present project but definitely help to know the potential into the area is rather good and in consequence considered as technically feasible (please see next figure).



Evaluación de Potencial Fotovoltaico ×

DATOS DEL ÁREA SELECCIONADA

| | | |
|---|---|---|
| **Areá seleccionada:** | 9.00 | Ha. |
| **Irradiación global horizontal:** | 5,834.00 | Wh/m²/año |

ESTIMACIONES

| | | |
|---|---|---|
| **Irradiación en un plano inclinado:** | 6,884.00 | Wh/m²/año |
| **Factor Planta:** | 23 | % |

SUPUESTOS

| | | |
|---|---|---|
| **Inversa de densidad de potencia:** | 1.60 | Ha/MW |
| **Factor por inclinación del panel:** | 18 | % |
| **Potencia de salida del panel:** | 240 | W |
| **Eficiencia total del sistema:** | 80 | % |

RESULTADO

| | | |
|---|---|---|
| **Número de Paneles:** | 23,438.00 | N° |
| **Capacidad instalable:** | 5.62 | MW |
| **Generación Anual posible:** | 11.30 | GWh |
| **Emisiones de CO2 evitables:** | 5.65 | Mt/año |

**Figure 24. PV potential evaluation** (CFE-SENER 2010)

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