Eco-efficient Prototype of Wastewater Treatment Plant Applying Clean Development Mechanism Methodologies – Mediterranean Countries

FIRAS FAYSSAL
Doctoral School & Faculty of Engineering
Doctoral School of Science and Technology (EDST), Lebanese University & Higher School of Engineering in Beirut, Saint Joseph University
B.P. 11-2806 Beirut & B.P. 17-5208 Mar Mikhael
LEBANON
ADEL MOURTADA
Doctoral School
Doctoral School of Science and Technology (EDST), Lebanese University
B.P. 11-2806 Beirut
LEBANON
MAZEN GHANDOUR
Faculty of Engineering
Faculty of Engineering, Lebanese University
B.P. 11-2806 Beirut
LEBANON
REMI DAOU
Higher School of Engineering in Beirut (ESIB), Saint Joseph University
B.P. 17-5208 Mar Mikhael, Beirut 1104 2020
LEBANON

Abstract: Municipal wastewater treatment is committed reducing greenhouse gases emissions in line with United Nations Framework Convention on Climate Change (UNFCCC) norms in order to preserve Earth's blanket and lower climate acute changes. Greenhouse gases emissions reduction is the avant-garde of municipal wastewater treatment technologies; however, the process requires particular segmentation of all phases to contain the excessive energy required for treatment. Consequently, Energy analysis is endorsed as essential to sustain a thermodynamic equilibrium of the treatment plant with its environment. Decarbonization, denitrification & phosphorus removal urge the exploitation of sustainable energy whether recovered or renewable to engine the treatment facility. This literature values compile the eco-design of wastewater treatment plant with the avant-garde technologies of greenhouse gases emissions reduction, considering environmental aspects at all stages of treatment process, targeting the lowest possible environmental impact throughout the plant life cycle to create a CO_2 -free facility prototype. UNFCCC introduced the greenhouse gases emissions definition in wastewater plants as a project design document for the Clean Development Mechanism (CDM) project AM00801 activity. The literature adopted this project and submitted it as a friendly user interface or a Software to model an Eco-efficient management strategy for wastewater treatment plant aerobic activated sludge type with the offset of environmental footprint measures based on decision making analysis, Input-output analysis, benchmarking and energy balance, net negative emissions including environmental declaration assessing the life cycle from costing, management, and sustainability perspectives.

Key-Words: WWTP, Energy consumption, Aerobic Activated sludge, Life Cycle Assessment, Decision-Making, Data Acquisition, Greenhouse Gas Emissions

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1 Introduction

The United Nations (UN) declared in the emissions gap report the GHG emissions approximately 58.1 gigatons of CO2 equivalent (GtCO2e) in 2019 [17], which leads to a significant indication of surface water runoff and wastewater discharge pollution specifically. However, the UN through UNFCCC affirmed environmental policy shifting in order to decrease waterways pollution. Under the Kyoto Protocol, emission caps were set for each Annex-I country [18], amounting in total to an average reduction of 5.2% below the aggregate emission level in 1990. Each country has a predetermined target of emission reduction as compared to 1990 level. No emission cap is imposed on Non-Annex I countries [18]. However, to encourage the participation of Non-Annex I in the emission reduction process a mechanism known as Clean Development Mechanism (CDM) has been established. The carbon markets are a prominent part of the response to climate change and have an opportunity to demonstrate that they can be a credible and central tool for future climate mitigation. Therefore, developed countries agreed to limit their GHG emissions, relative to the levels emitted in 1990 or to substitute the excess emissions with carbon trading by investing in emissions reduction in non-developed countries (such as Morocco & Lebanon subject matter of literature's case study). Municipal wastewater utilities are a direct and effective target for regulation and control, the matter that has been reflected in Kyoto Protocol and all ensuing conventions and agreements such as GHG emissions reduction process integration. Table 1 shows all emissions that currently are in common practice for municipal WWTPs

Table 1: The global warming potential of six major greenhouse gases [19]

Name of the Gas	Global Warming Potential	Atmospheric Life (years)
Water Vapor (H_2O)	0.1 to 0.23	Few days
Carbon dioxide (CO_2)	1	5 to 200
Methane (CH_4)	21	12
Nitrous oxide (N_2O)	310	114
Hydrofluorocarbons (HFC)	140 to 11,700	1.4 to 260
Perfluorocarbons (PFC)	6,500 to 9,200	10,000 to 50,000
Sulfur hexafluoride (SF_6)	23,900	3200

GHG emissions reduction methods primarily facilitate the decarbonization in all treatment processes from preliminary to tertiary mainly aeration at secondary phase and require energy in form of electricity thus exploited methods should account to decrease biological oxygen demand for all point of sources, treatment and GHG emissions reduction. CDM Mechanisms consider a baseline project and leakage emissions from electricity consumption and monitoring of electricity generation for all influential detected types of emissions throughout the treatment process (carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O)). This literature is concerned mainly to develop the AM0080 Project (Mitigation of greenhouse gases emissions with treatment of wastewater in aerobic wastewater treatment plants) into an Eco-efficient project where an application of sustainability assessment tools is translated into a user-friendly interface (1) resuming the techno-economic analyses, (2) systematically examining the sustainability aspects of WWT processes, (3) assessing all environmental, social and economic dimensions, (4) recovering energy required for both treatment functional processes and emissions reduction processes through management of resulting biosolids. The methodology adopted to support informed decisions making via data acquisition, filtration, benchmarking and decision-making tools in order to assure the execution of WWTP eco-design and instantaneous improvement actions enhancing sustainability, without burden shifting. The main focus in the literature is to develop, upgrade, simulate and model the proposed baseline project into a prototype exploiting most available technologies of wastewater treatment in Mediterranean Countries specifically Non-Annex I countries (or non-developed countries).

2 Methods

2.1 Goal and scope definition

The goal of this study is to (1) innovate a user-friendly interface (2) where embedded all simulated models for an eco-efficient prototype WWTP (3) involving all available technologies and environmental analysis (4) comparing the life cycle impacts to baseline project referring to CDM mechanism (5) using applicable mathematical algorithms and methods.

We shall evaluate four different management strategies in that context for the purpose of generating such software: (1) Data Acquisition (2) Energy Balance (3) Life Cycle Assessment (4) GHG emissions Definition & Reduction.

life cycle inventories involved both baseline and project data on process simulation creating a record of input and output flows for plants in Morocco (UNFCCC Case study), Lebanon (All country's functional plants), Greece (the most advanced AAS plants) & France (Self-sufficient WWTPs AAS). Such sampling included inputs of wastewater parameters, energy consumption, and emissions releases based on comparable data (Mediterranean countries) of both industrial, developing and non-developed countries. This study is innovative in inaugurating, for further expansion of focused economic and energy performance, a valid referential comparative of WWTPs in countries at Mediterranean coasts using types and technologies other than the study subject matter (AAS).

In line with UN regulations, Mediterranean municipalities are mandated to implement GHG emissions reductions guidelines that are ultimately on paper with the goal of protecting Mediterranean surface water and improving environmental quality that entails eventually the exploitation of novel treatment technologies [20]. However, the cost of implementation is typically the major factor for decision making. Accordingly, technologists and legislators shall benefit of the current literature outcomes either the environmental impacts fallouts using LCA or the economical results using CDM project accreditations through CO2e savings or CER (certified emission reduction or carbon Credit which is the reduction of 1 ton of CO2 emission from the baseline project activity) which can be evaluated in terms of energy saving. This study is based on a set of equations extracted from CDM mechanisms and algorithms formulated on JMP Pro14, rendered and simulated into models on MATLAB.

The outcome is gathered up on a user-friendly interface which is the resulting Software of the literature out of flexibility and ease of use considerations with commercial intents. The target of the literature defined in the submitted proposal to the CDM committee embodied in the resulting software, is to enhance Carbon Trading through different approaches included and implemented in the submission. The current submission concerns are the following: (1) Energy efficiency for new or makeover projects (existing or proposed baseline plant) by means of energy recovery and exploitation of allowable renewable energy (including and not limited to: Cogeneration, installing an anaerobic digester, improvements or switching to less carbon intensive energy sources, solid management, Reducing the frequency of the transport activity) (2) Environmental Impact (including and not limited to: LCA, LCI, LCAI) (3) Resulting reduction of any category of greenhouse gas emissions.

In this study, the mined for performing data to be incorporated into a master list establishing the adopted scenarios, are: (1) the baseline set by UNFCCC at Fès Morocco, (2) the mean WWTP in Lebanon (referring to CDR study), (3) Greece self-sufficient plant parameters [21], (4) France Neutral plant parameters [22]. All reported data from sample WWTPs were given equal weight in this study and reference was always the CDM mechanisms listed baseline parameters to develop an eco-efficient prototype with three different levels of energy efficiencies (listed scenarios). In condensing this grouping to one prototype WWTP processes for an Open input-output LCA adjustment, the resulting linear mean of values was used for the process inventory. The intention of this method was to create a process representative of the project set by CDM program by taking surveyed data of Mediterranean countries from multiple significant plants. This assumes that studied and surveyed plants are representative of plants as a whole and that the data acquisition method has comparable results to the set baseline uncertainty analysis for discussion characterized the potential impacts of the variability in literature values and addressed possible alternative assumptions. Values from adopted scenarios are used to put boundaries and deduce benchmarks on emissions and energy consumptions for baseline used technologies and proposed project submission CDM-PDD. No alternatives were addressed as all varied operating conditions and necessary inputs as suggested in baseline and from modeled acquired parameters and variables, were included and simulated without detected flaws. The outcome of modeled values was proposed for the new inventories and reassessed for the environmental impact study applied to the baseline project. Differences between proposed scenarios were highlighted in models with mention to potential grounds and odds and adjustment coefficient was integrated to emissions equations to unify the study of different means.

2.2 System Boundaries

The current study implemented a combination of novel technologies in WWT sector with the intention of meeting GHG emissions reduction goal set by CDM mechanism and as such uses the best mechanical, chemical & biological practices to assure energy self-sufficiency or neutrality of the project plant; which allows decision-makers to easily compare the estimated financial & environmental impacts incurred by meeting the set goals.

The functional unit for comparison in this study is kilogram (kg) of CO2 equivalent removed or saved.

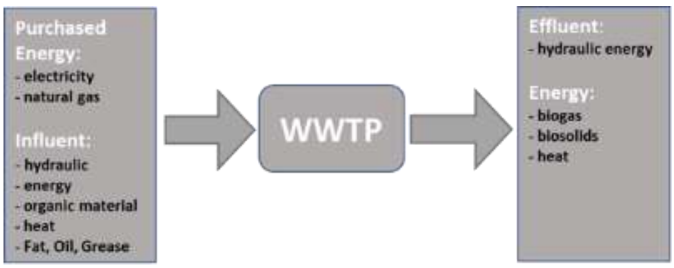


Figure 1: System Boundaries – Energy Weight in & out

Comparisons were performed based on total supply chain environmental impacts, with highlights on the local energy consumption and fugitive emissions due to their high impacts. The approved methodology included in PDD-CDM submission assumed high energy consumption and fugitive emissions that have relatively simple computation and expected to have a useful lifetime of 20 years as per baseline definitions. In order to tender a set of algorithms adjusting to parameters' variations to define an immediate precise carbon footprint calculator, data acquisition method, energy balance process and LCA of baseline WWTP, comparable scenarios should be well investigated accordingly.

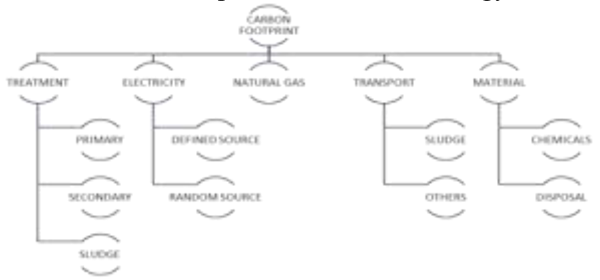


Figure 2: Carbon Footprint Calculation Scheme ISO14067

2.3 Scenarios Description

The default scenario is a simple AAS WWTP at Fès Morocco with defined parameters and variants through the AM0080 program. the bar against which all other scenarios are compared have been selected based on variables that should be controlled with both lower and higher limits.

	Lowest BOD_5	Lowest COD	kWh/m³-billing	Highest BOD_5	Highest COD
WWTP1 (France)	137.98	289.07	0.842	294.55	644.4
WWTP2 (France)	82	238	1.77	449	707
WWTP3 (Greece)	192	521	1.58	491	1375
WWTP4 (Greece)	164	468	0.24	515	1181
WWTP5 (Morocco)	42	321.5	8.68	241.33	496.5
WWTP6 (Morocco)	35	273	2.6	310.67	651.8
WWTP7 (Lebanon)	87.25	298.63	1.17	404.5	765.38
WWTP8 (Lebanon)	307.36	784.8	0.8	633	1990.4

Table 1: default scenario of WWTPs AAS Parameters & Indicators

the approved scenarios by the CDM committee were restricted to a single mean sample from each of France, Greece, Morocco & Lebanon. Knowing that parameters extracted from France & Greece plants represent factual data acquisition from the year 2020 along with listed parameters for Morocco Fès plant (baseline) and mean parameters from Lebanon plants also for year 2020

2.4. Process Description

2.4.1. Data Acquisition & Fault Detection Method

Data validation, online monitoring of difficult-to-measure variables, predictive maintenance, system and energy optimization, and targeted water reuse are the essentials of big data focus to improve WWTP operations. Therefore, big data integration will have the greatest influence on process control at the WWTP to monitor and manage treatment operations, for both upper and lower limits of process variables. Data from case study WWTPs is collected at various times, ranging from continuous online sensor measurements to quarterly laboratory results. Due to the difficulty of combining data of multiple frequencies and formats, traditional data management separates data by source. Scaling data to a single time period is a popular mathematical strategy for dealing with varied data frequencies. However, because WWTP data are time-dependent, co-correlated and the relationships among variables are related to one another, and nonlinearly related, this method cannot be used for datasets with a considerable difference in frequencies. Effluent quality variables can change differently over time (Table 2), and they frequently change nonlinearly in connection to other process variables, making it difficult to pinpoint the reason for change between sample events. The frequency with which the treatment process is monitored is highly dependent on the analysis' purpose and the process' parameters.

Timescale	Feature
Slow (days-weeks)	Solids retention time (SRT) Hydraulic retention time (HRT) Transmembrane pressure (TMP)
Fast (seconds-minutes)	Dissolved oxygen (DO) Nutrient concentrations Turbidity Conductivity Flowrate

Table 2: Time Lap of WWTP AAS Pollutant Proceeding

Due to all aforesaid, the combination between MCDM (Multicriteria Decision Making) and stepwise regression methods has been found the best method to represent the irregular nonlinearity of WWTPs case study behaviour and achieve a correlation that can be read by the indicator model itself and through the established bridge model between different correlated parameters on loophole basis [11]. All models of the study hereinafter basically are likewise based and all nonlinear trends reflected thru the models and bridge models. If nonlinear and nonstationary activity is found, modelling nonstationary behaviour can be done in one of two ways: accounting for a known, or predicted, underlying trend, or limiting the temporal window over which a model is trained. Given the difficulty of modelling nonstationary behaviour in the WWTP (Table 3) small time frames may be the best option for achieving approximation stationary and normal behaviour, which is the case of analysed prototype.

Feature	Frequency	Structure	Proceeding
Water quality	Daily-Monthly	Numeric	5-day biochemical oxygen demand, alkalinity, nutrients
Water quality	Second-Minute	Numeric	Temperature, dissolved oxygen, pH, nutrient concentrations: sensors
Equipment monitoring	Second-Minute	Categorical	Power status
Equipment monitoring	Second-Minute	Numeric	Operating speed, flowrate, pressure
Operating setpoints	Second-Minute	Categorical	Peak or normal operation for flow
Operating setpoints	Second-Minute	Numeric	Runtime for batch operations

Table 3: Monitoring Proceedings in WWTPs Sampling with Data Acquisition Frequency and Model

Model-based control could be used to forecast what a variable value should be under particular situations. Model predictive control contrasts predictions from mechanistic models with real process observations. Then defects are discovered as deviations from the model. The model can be derived from theory or empirical trends and can be used to approximate new process variables. Instead of directly monitoring the variable of interest, a relationship between variables can be discovered, which exactly was the basis of the current study models' connection due to the complexity and variability of parameters and indicators. Therefore, it is essential to comprehend the entire strategy of data acquisition and clustering process, in order to proceed in a planned, target-oriented method and to secure the utmost possible conclusion. Consequently, frameworks for formalizing the knowledge encounter process have been developed through experimental feedback and mathematical applicable processes. These process models explain the knowledge outcome project's life cycle and give a roadmap for executing similar projects under any comparable circumstances. The UNFCCC AM0080 Pilot project depicts the process model used in the procedures discussed in the submission. The model, that can be generalized at the scale of standardization to all WWTPs subject matter, is based on a combination of an industry-oriented standard process for DA model and created by a consortium of significant proven algorithms reflecting models of all required and necessary applicable KPI's for AAS WWTPs type. Hereafter a detailed elaboration shows the adopted algorithms and models of all indicators leading to GHGs emissions arithmetical definition. The process is engineered of six interconnected, highly participatory, and iterative phases: (1) A thorough understanding of the issue defining problems and setting objectives are the start in this stage based on strong relativity indicators. (2) Data comprehension, after all data is collected, verified, and merged, is essential to acquire prior knowledge of raw data extracted from plant management. The data's relevance in relation to the objectives shall be confirmed at that stage. (3) Preparation of data at that phase determines which data will be used and in what format. As a result, this step includes significance testing, data cleansing, deriving new attributes, and feature selection and extraction. The data is now in a format that can be used with the tools chosen in the first stage. Bugs are being filtered with a specific regression model as shown hereinafter. (4) Many approaches could be used to extract knowledge from the pre-processed DA. Extracted knowledge can take any shape, such as a list of rules or a model which is the case witnessed after generating all KPI's models. This phase evaluates accuracy and generality. (5) Assessment of newly acquired information is the process to interpret and segregate outcomes between normal feedback (Déjà vu) and new data requiring further assessment. If there are any new or intriguing patterns, they shall be recorded and the model notes here a looping to rectify according to the corrected pattern. Within the guidelines noted in CDM mechanisms, all feedback should be processed as repetitive knowing all parameters. (6) The deployment of the system is all about deciding on a distribution strategy: What should be done with the newfound information? and where should it be applied? Upon trials and debugging the answers shall apply in due course and reflected in generated models. Briefly, Process abnormalities in WWTPs case study subject matter can be caused by a variety of system failures or changes in circumstances. A change in influent quality, an outbreak of treatment-inhibiting microorganisms, irregularities or damage to treatment units, mechanical failures, or sensor failure are all examples to crucial circumstances that might undergo the DA and modelling/modelled process. When creating a fault detection algorithm/software, it's fundamental to think about how versatile an analytical technique is, and what kind and range of errors should be recognized. Many variables could be changed if a sensor fails, especially that the sensor's measurements are used in a control loop which would duplicate the error at every chain of data processing. A sensor malfunction, on the other hand, may only influence the measured sensor variable if the sensor's measurements are not included in a control loop. Control charts are the most important tools for determining whether a process is in control at a glance. As well as the principal component analysis method that is a widely used statistical method for

continuous monitoring of a wide range of variables. It captures the correlations between linear combinations of variables rather than the variables themselves. Beside the main statistical role, the partial least squares method can detect errors in a separate linear combination of the measured variables in the same way as executing the initial data pool of extrapolated WWTPs [15].
Decision Making is the adaptive or flexible decision method that can be used in uncertain conditions, as due to the fact that the future of WWTPs is uncertain and unpredictable, robust options tend to be more recommended than optimal options. On the other hand, the best option is more suitable when the future can be predicted [14]. The purpose of decision making is to identify full-bodied strategies, which can adapt or perform well under uncertain situations in the future. The method is helpful for decision makers in long-term consequences. The fundamental steps for automated decision making are to: (1) identify the issues and set a goal; (2) find information, strategies, risks and select a robust strategy; (3) take an active towards the goals; (4) determine whether the strategy is effective; and (5) update and resolve the strategy. The last step is an essential one because if the strategy is not effective, decision makers can change strategies until they meet their goals [12]. Pilot project didn't adopt any automated decision-making methodology, therefore the PDD submission had to assure MCDM as the decision-making methodology to be followed for all ascended uncertainties along with stepwise regression logic where necessary and control charts logic for fault detection. Finally, the summarization logic is used to gather all models to extract the GHGs emissions as a linear trend according to all variabilities imposed by change of parameters.

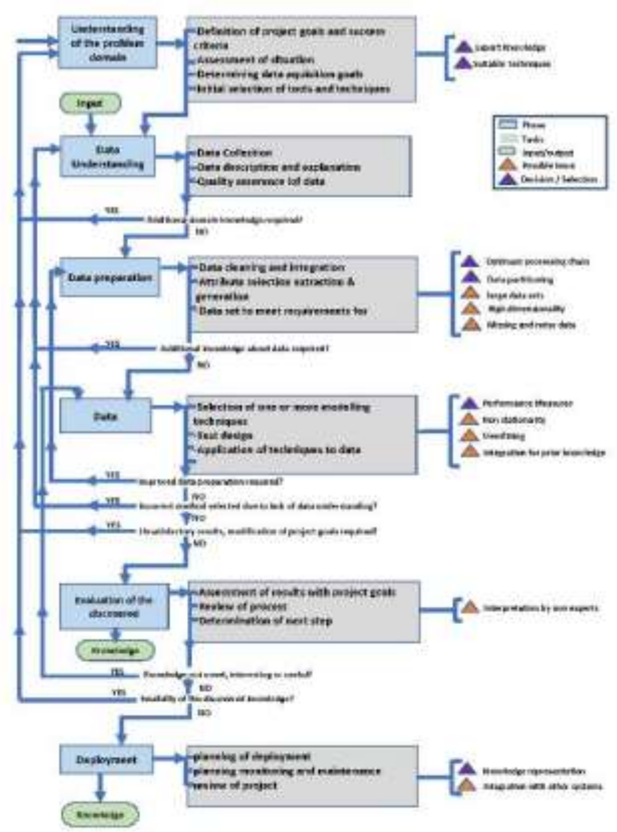


Figure 3: Framework of Data Acquisition & Method Selection

2.4.2 Energy Balance Process

Wastewater utilities consume approximately 2% to 4% of the power at national level as an average at all Mediterranean case study countries, which is typically obtained from the grid. WWTP's secondary treatment phase is the processes consuming the largest quantities of power. Reducing process energy consumption in WWTP starts with a process energy survey. The mission of this study is to provide all conceivable aspects that may help in the transition to energy neutrality in WWTPs with comparable examples from industrial developed countries (France in our case study), which will be expanded further in this literature using arithmetic models based on UNFCCC methodologies. The sources of energy in wastewater were explored, as well as several indicators for expressing energy consumption, using experimental cases of operational WWTPs in the Mediterranean countries: Lebanon (non-developed countries' sample), Morocco (baseline case as indicated in AM0080 project), Greece (Developed country with high potentials of sustainability) and France (Industrial developed country with energy neutral plants comparable case study). The operational methods and technology upgrades of the WWT processes were assessed, as well as the different lanes for energy consumption reductions. The methods for recovering the potential energy hidden in wastewater, as well as the use of renewable energies in WWTPs, were then explained and modelled. The available assessment methodologies were introduced, which may support the analysis and comparison of WWTPs in terms of energy and GHG emissions. Finally, successful case studies on WWTP energy self-sufficiency were listed in a threshold prototype comparable to baseline project and its potential advancement. The literature's innovative project, the Software, was presented after analysing the results and discussing energy saving strategies and energy conservation measures in order to reach the GHG emissions computation through the models simulating energy requirements and potential savings for WWTPs. For this purpose, wastewater industry's energy demand, distribution and performance were projected to account for an average of 1.8% of all electricity consumed at the national level for developed Mediterranean countries depending always on country's energy sustainability approaches with differences in relativity and data availability. However, WWT and transportation sectors consume approximately 3% of total electrical power produced in a non-developed country according to the annual report of energy consumption worldwide published by UN Stats, the statistics division of UN [2]. Nevertheless, all studies anticipated an increase of at least 20% within the next decade to the amount of power required for WWT in non-developed and newly developed countries, leading to a significant increase in CO2 emissions and resource consumption. The amount of energy used to treat wastewater is influenced by a variety of factors and determined by the following: the location of the plant, its size, the type of treatment process and aeration system used, the effluent quality criteria, the facility's age and lifetime and the operators' expertise and abilities. Despite the fact that the average energy consumption per cubic meter of treated wastewater (kWh/m3) is rather consistent between countries, the amount of energy required for operations varies greatly amongst WWTPs and requires more accurate indicators to reflect the actual status. For analysed WWTPs, the reported figures on specific energy consumption range from 0.25 kWh/m3 to 0.50 kWh/m3 [2] . For WWTPs using modern biological removal systems with multiple energy-saving techniques, the reported figures on specific energy consumption can be as low as 0.25 kWh/m3 [7]. The climate in which the WWTPs were run proved to have only a slight impact on energy consumption, with colder temperature circumstances possibly resulting in lower energy consumption than hot and humid environments [15]. Consequently, the provided results from CDM baseline indicated that the target average energy consumption of WWTPs was around 0.06 kWh/m3 to 0.20 kWh/m3 without being able to precise a threshold due to the lack of benchmark, which was much lower in certain more developed countries. Regardless of the size of the WWTP, the biological treatment phase consumes the majority of energy required for the whole plant, which can account for up to 75% of total consumption [15].

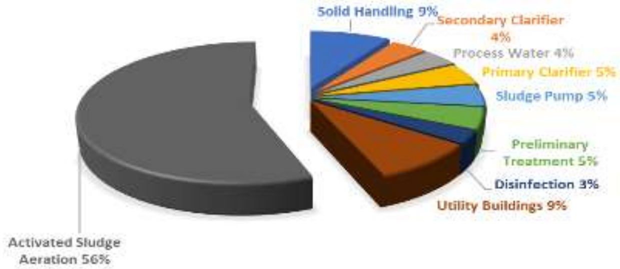


Figure 4: AAS WWTP Power Consumption Distribution

Approaches to Energy Balance in AM0080 Pilot Project:

wastewater contains a quantity of energy that can be recovered, proven thermal energy content estimated at 75kWh/P.E./a, proven energy potential from organic matter estimated at 153kWh/P.E./a [9], and proven hydraulic potential energy depending on inflow rate and available hydraulic height. Moreover, wastewater energy consumption is relevant to national electric energy consumption accounting approximately for 30% of total energy consumption of municipalities. The electric energy saving potential is high and proven estimated at around 25% [15]. The proven recovery from biogas production is around 17kWh/P.E./a of electric energy and 27kWh/P.E./a of recuperable thermal energy [2]. A detailed analysis of the applicability of these facts of energy consumption, saving and balance to the AM0080 pilot project are well elaborated in the generated models and simulation. Figure 5 below shows the typical energy flows produced by AAS digestion in Fès WWTP, that convert the chemical energy content of COD to electricity and thermal energy. Consequently, the biogas energy recovery can cover up to 62% of total energy requirements. (Refer to the biogas model renewable energy section hereafter). the energy balance of conventional WWTPs shows that the most important energy consumers are the aeration system (60%), wastewater pumping (12%) and anaerobic digestion (11%), which together account for the 83% of global energy consumption of the plants [10]. The main purpose of determining the role of energy efficiency in sustainable WWT processes for AM0080 is to reach an optimum prototype AAS WWTP where all energy recovery and external renewable resources are ultimately used and GHGs emissions are diminished to the maximum possible [8].

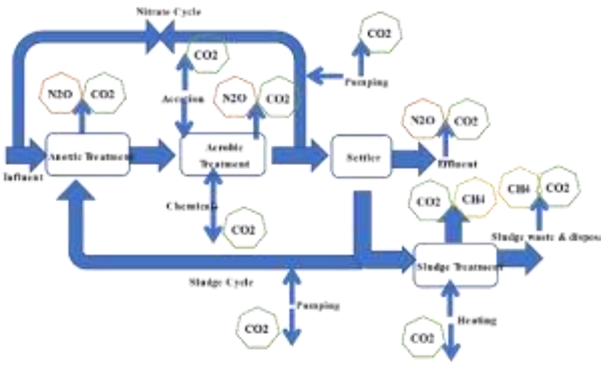


Figure 5: GHG emissions during treatment process at Fes WWTP

This study adopts proven theoretical methods to produce models on energy efficiency, evaluating appropriate sustainable WWT technologies, and applying to the pilot project. Energy efficiency plays multiple roles such as sustainable growth and advancement, and economic development through the application of the set mechanism. It can also lead to carbon minimization resulting in reducing climate change however many exclusions for the sake of simplification were applied by CDM to avoid an optimum GHG emissions reduction.

A- Design Process Guidance: is a circular process that aims at continual development over time and require beside a robust methodology, starting with predesign operational advanced technologies (mechanical, biological & chemical), accurate DA, steady LCA and LCC, some technologies that provide a fast data input combination and decision making that would be achieved through IoT. Relying to a complete structure of control, WWTP function should follow a complex hierarchy based on both input data and results at the same time. All predesign measurements were reported by CDM as included in Fes's pilot project AM0080, the current mechanism according to both tender document, execution and operational records. Some of the main design measures audited, surveyed, simulated and modelled in this literature are: (1) Pumping: pumps selection, pumping system peak, Continuous calculation of system energy performance, Evaluation of cost assessment including energy, operation and maintenance costs, Equipment management. All these factors were considered in AM0080 methodologies and included in related framed equations and tools [4]. (2) Aeration systems of the Fès facility in the secondary treatment process account require up to 30-60% of total energy used at the conventional AS WWT system [7]. Adding dissolve oxygen sensors and automatic controller, fine bubble diffusers, proper blowers, and variable speed motors, assure constant evaluation of oxygen need and DO control all over the clock. All these factors were translated into equations and algorithms rather than models to be incorporated in software. (3) Solids Handling: Solid volume reduction ensures energy requirement and solid handling. Anaerobic digestion is the method implemented in this pilot project generating biogas production and heat. All mentioned factors were translated into equations and algorithms rather than models to be incorporated in software. (4) Ultraviolet system method is partially used for tertiary treatment so the disinfection system takes place at WWT facility. The upgrade of this option further than baseline conditions was disregarded.

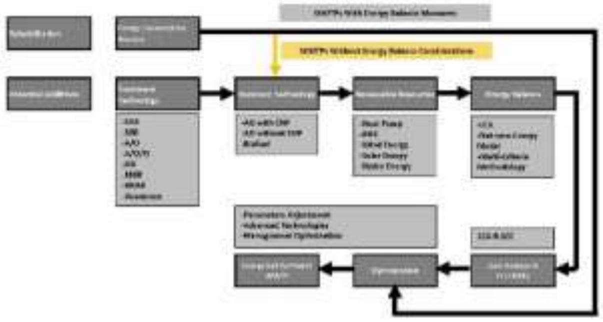


Figure 6: Energy self-sufficient WWTP Process, Theoretical Analysis to Practice

Each technology has different removal efficiency and can be evaluated on past experience, full-scale, or pilot studies. Existing pilot project is a baseline considered as the reference to the additions made.

Process	**Recommendations**	**Energy Savings (%)**
Influent Pumping	Pump Control based on flow	10%
	Conducting Inflow & Infiltration long term analysis	35%
	Rehabilitation of Pumps	20%
Aeration	Short Term strategy: Mixers off with Aerator On	90%
	Short Term strategy: Replace DO meter	10%
	Long Term strategy: integrate DO meter to control	40%
UV disinfection	Short Term strategy: Replacing Bulbs with low emissions	50%
Solid Handling	Retrofitting sludge feeding network from thickener	100%

Table 4: Energy Saving Recommendations on Mechanical Process

Figure 7: Initial Model Scope of Work

B- Resource Recovery: Two nutrients in wastewater are phosphorus and nitrogen can be used to produce fertilizer and reduce GHGs emissions. Furthermore, landfill gas technologies can capture methane or biogas using anaerobic digesters. These technologies should be applied for resource recovery in WWTPs [15]. The pilot project disregarded these two essentials energy recovery factors that have been added to the PDD submission after being simulated and modelled.

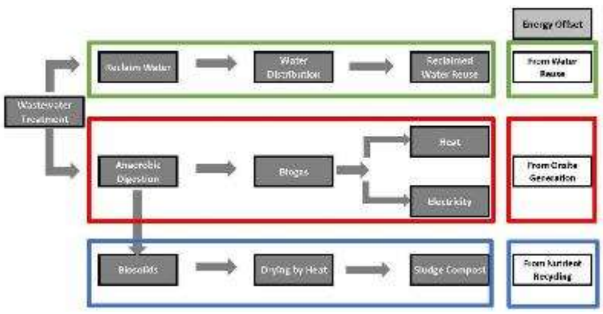


Figure 8: Recovery Diagram in Fès WWTP

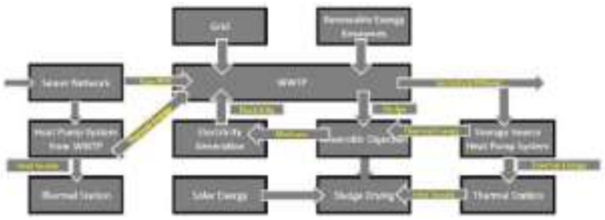


Figure 9: Energy utilization diagram of Fes WWTP

C- Renewable Energy Exploitation: The WWTSs should save energy consumption by reducing energy used and implementing technologies that can produce renewable energy [16]. Local governments should consider applying energy-saving measures in WWT facilities [11]. The goal is to improve energy efficiency in the plant. WWTP at Fès considered developing less energy consuming equipment however no renewable energy has been exploited to make Fès zero energy plant. PDD considered this criterion as an essential factor of developing additions whether solar or wind that are both simulated and modelled.

2.4.3. Life Cycle Assessment & Life Cycle Costing

Technological advancements highlighted in CDM mechanisms are paving the way for new behaviours to support the circular economy by recovering resources from wastewater. The use of LCA and LCC in the development of technical solutions for treating wastewater and recovering by-products is a prerequisite by UNFCCC pilot project submission which is evaluated based on employing unique novel technology configuration to process and recover wastewater. Therefore, the current assessment focuses on finding hotspots and potential design improvements. Furthermore, the construction of a unified strategy for projected LCA and LCC is demonstrated in order to improve the robustness and consistency of the project pilot systems' analysis. The impact and cost of treatment are significantly depending on the effluent composition, according to the investigation specifically, whether the recovery of biogas and treatment of wastewater can offset the treatment systems' impact and expense. preliminary analysis indicated that this is achievable. For the baseline study, estimates of GHG emissions were acceptable with many exclusions considered. However, adding all excluded sources of GHG emissions to the baseline, it is predicted to reduce at full scale the energy consumption, as well as operational costs and increase revenues at the level of emissions CERs and expenses saving.

The LCA technique adopted follows ISO 14040 and 14044 as recommended by AM0080 program guidelines [6]. As a result, it is believed that comparable available resources are much cheaper at the level of emissions yet the energy neutrality of WWTP necessitates the neutrality of environmental impact, accordingly a project-wide methodology has been established out of the existing pilot project. The initial stage's goals are to compare each baseline set by CDM to the reference case or simulated baseline formulated in that study, while the project's ultimate and final goal is to compare each of the baseline and monitoring for both DA (with and without exclusions). Background data was gathered from the CDM methodologies and tools. Additional data is based on bench scale measurements and simulations with the addition the study proposed to the UNFCCC program. The simulation achieved in the current analysis can calculate a variety of geochemical processes involving wastewater and biogas emissions, beside sludge management. the technology units employed in the pilot project from which data was obtained are well defined, referring to ISO 14040 and 14044 [6]. The scope of this study is limited to the major actor of financial and environmental LCC, which comprised listed purchase costs (CAPEX) by CDM in tender project, operational costs such as energy and other resource consumption, maintenance and repair expenses (OPEX), and end-of-life costs such as collection and recycling costs. Revenues from recovered by-products are also accounted for as negative costs (except recovered energy) [1]. The pilot project is indicated to have a 20 years life span as a functional plant (15 years is the standard lifetime set for WWTP). Nonetheless, the project's next steps (UNFCCC submission) are to be conducted with a comprehensive environmental LCC, which will include both internal and monetized external environmental costs, such as those related to global warming once defined by the Software subject matter. The chain of process below represents the integrated Method approaching LCA & LCC with the goals of aligning the overall approach and main LCA components; develop an understanding of the project pilot, technologies, data, and simulation challenges; provide an initial LCA and LCC and identify the main hotspots; and identify preliminary design implications and where additional efforts to improve data quality may be required.

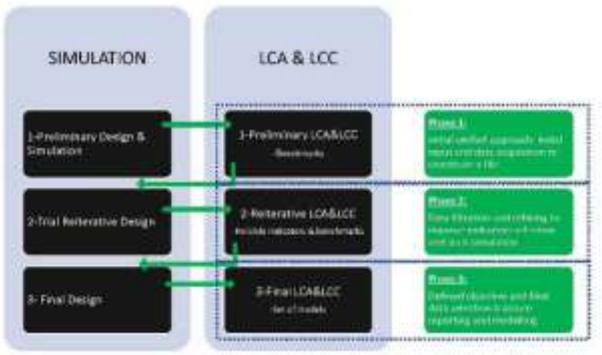


Figure 10: Flowchart of LCA & LCC Approach Phases

The AS treatment system has substantially higher energy requirements than any other treatment type due to the aeration machinery operating almost all day [2].

Equipment	Power kW	Operation Time	Control
Aerator	56	Continuous	VFD fixed speed
Centrifuges	30	10 to 20 hrs./week	VFD flow speed
Influent Pumps	13	Continuous	VFD flow speed
Blowers	11	Intermittent	Fixed Speed
Mixers	3	Continuous	Fixed Speed
UV System	7	Continuous	Fixed Bank

Table 5: Major Energy Consumers for WWTP AAS

These findings are consistent with pilot project operations factsheets. The biggest contributor to the effect categories of abiotic depletion and global warming is energy consumption by fossil fuel and electricity, which explains why AS has a higher impact among all categories [13]. The objective of the study beside the software, is the background engine where all indicators the most important amongst energy consumption, benchmarking, recovery and renewables, to be well reflected through numerical trends and algorithmic models screening the evolution and interaction of each factor and parameter. The objective of establishing a set of key performance indicators computed and modelled is to gather all models with a convenient correlation algorithm that defines bottom line an accurate amount of resulting GHGs emissions from treatment process referring to CDM mechanism, AM0080 project and tools specifically [3].

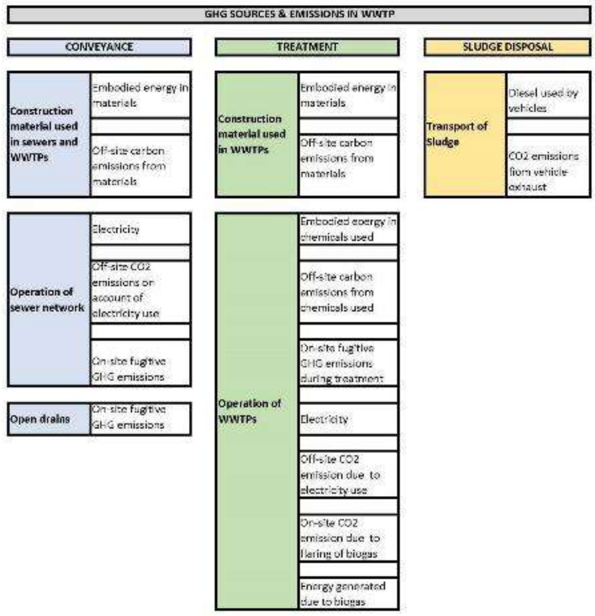


Figure 11: GHG Emissions Sources & Category

3.GHG Emissions Reductions

The approach for calculating and analysing the carbon footprint of baseline WWTP is extended from the CDM booklet by UNFCCC [3]. Accordingly, CF minimization has been prioritized to include in plants: Electricity, heat, chemicals, fossil fuels, transportation, and more with the code's advancement, however, GHG emissions considered CO2, CH4, and N2O main emissions to be assessed as a part of Kyoto Protocol. The assessment may be used at two stages of the CF reduction process: (1)

while deciding on a plan to minimize GHG emissions, the CF identifies the elements that have the largest environmental effect; (2) CF evaluates the efficacy of the actions taken to improve the energy balance. Furthermore, calculating the CF allows WWTPs management to control GHG emissions contributions [5]. Through the AM0080 project, the UNFCCC encouraged the evaluation of the CF of WWTPs from a life cycle perspective and offered a pilot project to standardize a set of equations to define the CF. The goal of this study is to turn this pilot project into a generic software system based on proven models and algorithms. CF calculation approach throughout the course of a plant's complete life cycle, splits the required LCCI data into two categories: direct & indirect emissions. However, plants are considered mixing both categories. Direct emissions are those controlled by the plant management system having no previous or subsequent technical history data inputs and outputs of plant's items causing GHG emissions. The complex model simulated in that study as the final result succeeded to define both emissions types and assure a better understanding of the result of energy efficiency and balance proposed at the phase of predesign or rehabilitation. Several different steps may be taken to achieve complete energy neutrality in WWTPs. The first major step would be reducing the current energy consumption of WWTPs which ranged between 0.25 to 1 kWh/m3 based on the mathematical calculation following the guidelines of AM0080 methodology. The most promising reviewed operational measures to reduce the energy consumption comprised aeration control strategies since aeration held the biggest share of the total energy consumption in Fès AAS WWTPs. However, innovating a LCA & LCC model (with the assistance of RETSCREEN as a feasibility portal for technical projects) helped to achieve further energy savings. Novel control systems, presuming IoT in our case, proved the possibility of significant reduction of energy for aeration, pumping, agitators, blowers reaching off more than 25% of the time while maintaining the same wastewater effluent standards. Furthermore, chemical and biological applications such as upgrades to nitrogen removal were able to reduce the required aeration energy by more than 60% using these new technological pathways of treatment. The second step towards energy neutrality was the increasing of on-site energy production by energy recovery through biogas sludge outcome production coupled with CHP engines and emphasis on renewable resources such as solar. The remaining electricity demand was managed to be recovered mainly by organic waste co-digestion to assure energy neutrality yet positive energy production. Reviewing all these successful methodologies in terms of energy self-sufficiency, linked to an executed monitored plant (Fès) proved the point that the predesigned or existing inefficient WWTPs should take a series of actions as reviewed in this literature to be turned into energy positive plants. Analysing the priorities of the actions separately, the literature proposed a CDM-PDD submission according to the resulting calculations and established a set of algorithms and models on MATLAB and histograms on JMP Pro 14 for each case study abovementioned depending on several operational environmental economic parameters. The advanced and complex analysis procedures, techniques and simulation tools (plant wide models) supported perfectly the decision-making to meet a sustainable self-efficient WWTP prototype. The adopted algorithms, and calculation methods used to generate models were all gathered in one user-friendly interface or Software and detailed in PDD submission. Different scenarios and treatment configurations have been simulated and documented by the CDM committee to illustrate the difficulty in accounting for all constraints imposed on the system. Therefore, the resulting model will serve as a basis to target challenges that will set the scene for determining directions of further developments within the UNFCCC project delimitations. There are also some tools within CDM methodology that divide the carbon emission system of Fès sewage treatment system into five aspects: material, energy, material consumption, carbon sink and resource. The focus of the CDM committee has been mainly on CO_2, CH_4, and N_2O GHG emissions factors. The basic input referred to the baseline project on which the additional improvement PDD submitted to the CDM committee yet with further extension to the data pool, energy balance components, energy efficiency aspects and emissions factors. Using the operation control method to determine the scope of GHG assessment of the WWTP, the raw GHG emissions must be 100% identified, and the emissions related to sewage treatment must be classified, as shown in Figure 12.

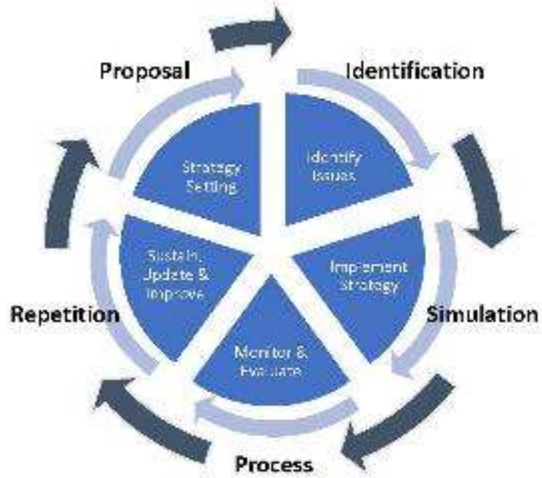


Figure 12: Assessment Scope Boundaries

The CO2, CH4, N2O and other GHG emitted by the sewage treatment plant are uniformly measured by the amount of CO2 produced. According to the GWP, the potential value of CO2 is 1, and the potential values of CH4 and N2O are 23 and 296 respectively, CH4 and N2O can be converted into carbon emission equivalent according to the corresponding potential values [6].

As per the IPCC agreement, it is the amount of CO2 directly emitted during sewage treatment. The CO2 emissions of biogenic wastewater are not included in the total GHG emissions, according to the "GHG Inventory Protocol-Corporate Accounting and Reporting Standards" [6], the total GHG emissions must be included. investigated and studied, the amount of CO2 produced during the operation of the actual sewage treatment plant, clarified to have the following factors affecting CO2 emissions as per the calculation formula of CO2 production:

MCO2 =Q*EFCO2 (1)

MCO2 - Biological treatment process emissions (g)

Q - Amount of sewage treated during calculation (m3)

EFCO2 - emission factor to the CO2 emission of the A2O process.

the calculation formula for CH4 generation is as follows:

MCH4=(TOW*EFCH4)-R0 (2)

MCH4 - CH4 emissions from biological treatment process (kg)

TOW - The organic matter content in sewage during the calculation period (kg)

EFCH4 - CH4 emission factor to the methane emission factor of the aerobic treatment process

R0 - The amount of CH4 recovered during the calculation period (kg) if no sludge digestion R0 =0

The formula for calculating the amount of N2O produced is as follows:

MN2O=TN*EFN2O (3)

MN2O - N2O emissions from biological treatment process (kg)

TN - Total nitrogen removal from sewage during calculation (kg)

EFN2O - N2O emission factor

During the operation of the sewage treatment plant, blowers, pumps, aeration equipment and other equipment consume a large amount of electricity, the carbon emissions of the purchased electricity during the production process are the indirect emissions of the sewage treatment plant, the calculation formula:

MCO2□E=E*EFCO2□E (4)

MCO2□E - Indirect CO2 emissions from power consumption (kg)

E - Power consumption (kWh)

EFCO2□E - The emission factor of electric energy consumption (kgCO2/kWh) Ref: Regional Grid Baseline Emission Factor

Some chemicals are used in the sewage treatment process, such as disinfectants, flocculants, etc., the formula for calculating carbon emissions of purchased chemicals:

MCO2□Y=ΣYi*EFCO2□Yi (5)

MCO2□Y - Indirect CO2 emissions from chemicals consumption (kg)

Yi - Consumption of chemicals i (kg)

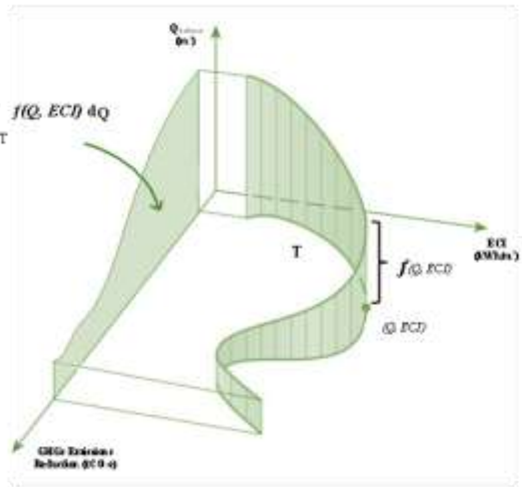
EFCO2□Yi - The emission factor of CO2 consumed by chemicals (kgCO2/kg)

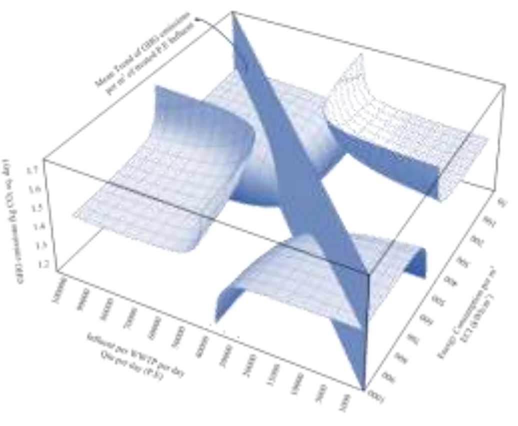
Each used chemical should calculate its CO2 emissions with corresponding emission coefficients. There are some other aspects of emissions, because it is difficult to obtain GHG emission factors for calculation, but should be estimated according to the actual situation of the sewage treatment plant, determine an appropriate ratio, and include it in the total GHG emissions. After a comprehensive analysis, it is determined that other emissions are 10% of the calculable emissions, which are included in the total GHG emissions of the sewage treatment plant.

A set of algorithms were formulated ruling GHGs emissions during all phases and translated into models to generate a user-friendly interface thesis subject matter. Models generated present GHGs emissions controlled and translated into the main generic model to generate Software interface literature subject matter.

4. Results and Further Improvements

In this literature, a cooperative decision support system for energy saving and production in WWTPs has been presented. The characteristics of this decision support system are aligned with the original research question and with the specific objectives presented in the UNFCCC program, CDM methodology, AM0080 project. The comparison between the baseline project objectives set by CDM and the obtained results using all necessary simulations and modelling, was shared step-by-step with the CDM committee and preapproved before publication. The proposed submission has been approved as a consistent model and presented to committee with a coherent structure enabling the integration of information, data gathered online, static data, and expert knowledge to provide decision making support along with the advancement and technologies adopted day by day in this field. Reaching the pre-validation phase is sufficient to positively answer the original and developed research questions.





4.2. Further Improvements

The set of Algorithms ruling GHGs emissions during all treatment phases, translated into Bridge Models to generate Final Model. The Final Model gathered all bridge models into Loophole Basis Control to assess all relevant projects via Software Interface. Amount of CO_2 directly emitted during WWT according to the "GHG Inventory Protocol" refers to equations (1), (2), (3), (4), & (5). GHGs Emissions Reduction Final Equation collecting all Variables & Parameters: $PE_{(EC,y)} = \sum_j (EC_{(PJ,j,y)} \times EF_{(EF,j,y)} \times (1+TDL_{(j,y)}))$

The data normalization of WWTP case study consists of the new perspective for this research where the application of a uniform set of measurement units and the calculation of comparable key performance indicators are the next level of automation in WWTP management and control strategy. This improvement, if ever achieved, would make the calculations faster, more stable and reliable, ultimately enabling the connection of managing a larger number of WWTPs with the same scale and conditions due course. An original approach based on the random forest algorithm was developed yet to be verified before submission and integration. it is useful to mention some of the forthcoming foreseen flaws and aims at a time to stimulate a discussion within the framework of this thesis knowing that these shortages were the stimulus of Software further development through continuous publications under CDM mechanisms and sponsor upon publication: application of software at larger scale, database upscaling, IT & WWT mix of knowledge challenge integrating core algorithms with fastest response, central computed connectivity to electrical grid, sewer mains database incorporation, widening the application to more WWT typologies, and commercial enhancement to interface.

5. Conclusions

This literature is the output of close follow up of baseline plant despite the redundancy and time salvage waiting committee response to proceed to the next level along with potential failure in equity with potential future developments identified and approved. This study shows the possibility to build a plant generic decision support system specifically oriented to optimize the energy balance in WWTPs and define GHGs emissions with remarkable reduction on climate change grounds. The two main lanes consist of 'market-oriented' and 'research oriented' projects. The first lane is the development of existing methodologies with the aim to deliver a service to the market. The second lane consists of the development of new methodologies for decision making support. at the moment, it is possible to report a strong interest from the UNFCCC and the author to continue exploring the topic with new projects and collaborations to assure the resulting interface will be further extended to the flaws noted hereabove, knowing that the current version of the generated software delivers the required complete report for an AAS WWTP energy balance, LCA, LCC & GHGs emissions with suggestions and recommendations for predesign or rehabilitation enhancement based on solid decision making support tools.

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