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

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ABSTRACT

Municipal wastewater treatment is committed to reducing greenhouse gas emissions in line with UNFCCC norms to lower climate acute change by reducing Greenhouse gas emissions. However, the process requires particular segmentation of all phases to contain the excessive energy required for treatment. This literature values compile the eco-design of WWTPs with the avant-garde technologies of GHG emissions reduction, considering environmental aspects at all stages of the treatment process, targeting the lowest possible environmental impact throughout the plant life cycle to create a CO_2-free facility prototype. UNFCCC introduced the GHG emissions definition in WWTPs as a project design document for the Clean Development Mechanism project AM0080 activity. The literature adopted this project and submitted it as a friendly user interface or Software to model an Eco-efficient management strategy for WWTP AAS 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.

KEYWORDS: WWTP; Energy consumption; Aerobic activated sludge; Life cycle assessment; Data acquisition; Greenhouse gas emissions; Energy balance; CO2 equivalent

INTRODUCTION

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 the 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 so as GHG emissions reduction process integration [1].

GHG emissions reduction methods primarily facilitate decarbonization in all treatment processes from preliminary to tertiary main aeration at the secondary phase and require energy in form of electricity thus exploited methods should account to decrease biological oxygen demand for all points 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

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types of emissions throughout the treatment process (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)). This literature is concerned mainly to develop the AM0080 Project (Mitigation of greenhouse gases emissions with the 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 treatments functional processes and emissions reduction processes through management of resulting biosolids [2]. The methodology adopted a support informed decision-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 of the literature is to develop, upgrade, simulate and model the proposed baseline project into a prototype exploiting the most available technologies of wastewater treatment in Mediterranean Countries specifically Non-Annex I countries (or non-developed countries) [3].

METHODS

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) involve all available technologies and environmental analysis (4) compare the life cycle impacts to baseline project referring to CDM mechanism (5) using applicable mathematical algorithms and methods [4].

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 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); [5].

In line with UN regulations, Mediterranean municipalities are mandated to implement GHG emissions reduction guidelines that are ultimately on paper to protect Mediterranean surface water and improve environmental quality which entails eventually the exploitation of novel treatment technologies. However, the cost of implementation is typically the major factor for decision-making. Accordingly, technologists and legislators shall benefit from the current literature outcomes either the environmental impacts fallouts using LCA or the economical results using CDM project accreditations through CO_2 savings or CER (certified emission reduction or carbon Credit which is the reduction of 1 ton of CO_2 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 [6].

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) using 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, (3) Greece's self-sufficient plant parameters [7], (4) France Neutral plant parameters [8]. 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 process for an Open input-output LCA adjustment, the resulting linear mean of values was used for the process inventory. This method intended to create a process representative of the project sent by the CDM program by taking surveyed data of Mediterranean countries from multiple significant plants.

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 the 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 the adjustment coefficient was integrated into emissions equations to unify the study of different means.

System Boundaries

The current study implemented a combination of novel technologies in the WWT sector to meet the GHG emissions reduction goal set by the 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 the kilogram (kg) of CO_2 equivalent removed or saved.

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 the PDD-CDM submission assumed high energy consumption and fugitive emissions that have relatively simple computation and are expected to have a useful lifetime of 20 years as per baseline definitions. To tender a set of algorithms adjusting to parameters' variations to define an immediate precise carbon footprint computation, data acquisition method, energy balance process and LCA of baseline WWTP, comparable scenarios should be well investigated accordingly [9].

GHG Emissions Reductions

The approach for calculating and analyzing 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 CO_2, CH_4, and N_2O 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 [10]. 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 to mix 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 emission 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/m^3 based on the mathematical calculation following the guidelines of AM0080 methodology. The most promising reviewed operational measures to reduce energy consumption comprised aeration control strategies since aeration held the biggest share of the total energy consumption in Fès AAS WWTPs [9]. However, innovating an 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 a 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 thru 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. Analyzing 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 the 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 the directions of further developments within the UNFCCC project delimitations. Some tools within CDM methodology 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 basis input referred to the baseline project on which the additional improvement PDD was 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.

The CO_2, CH_4, N_2O and other GHG emitted by the sewage treatment plant are uniformly measured by the amount of CO_2 produced. According to the GWP, the potential value of CO_2 is 1, and the potential values of CH_4 and N_2O are 23 and 296 respectively, CH_4 and N_2O can be converted into carbon emission equivalent according to the corresponding potential values [11].

As per the IPCC agreement, it is the amount of CO_2 directly emitted during sewage treatment. the CO_2 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 CO_2 produced during the operation of the actual sewage treatment plant, clarified to have the following factors affecting CO_2 emissions as per the calculation formula of CO_2 production:

$$MCO_2 = Q * EFCO_2 \qquad (1)$$

MCO_2 - Biological treatment process emissions (g)

Q - Amount of sewage treated during calculation (m^3)

$EFCO_2$ - emission factor to the CO_2 emission of the A_2O process.

The calculation formula for CH_4 generation is as follows:

$$MCH_4 = (TOW * EFCH_4) - R0 \qquad (2)$$

MCH_4 - CH_4 emissions from biological treatment process (kg)

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

$EFCH_4$ - CH_4 emission factor to methane emission of aerobic process

R0 - Amount of CH_4 recovered during the calculation period (kg)

The formula for calculating the amount of N_2O produced is as follows:

$$MN_2O=TN*EFN_2O \qquad (3)$$

MN_2O - N_2O emissions from biological treatment process (kg)

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

EFN_2O - N_2O 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:

$$MCO_2{\cdot}E=E*EFCO_2{\cdot}E \qquad (4)$$

$MCO_2{\cdot}E$ - Indirect CO_2 emissions from power consumption (kg)

E - Power consumption (kWh)

$EFCO_2{\cdot}E$ - Emission factor of electric energy consumption ($kgCO_2/kWh$)

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

$$MCO_2{\cdot}Y=\Sigma Yi*EFCO_2{\cdot}Yi \qquad (5)$$

$MCO_2{\cdot}Y$ - Indirect CO_2 emissions from chemicals consumption (kg)

Yi - Consumption of chemicals I (kg)

$EFCO_2{\cdot}Yi$ - Emission factor of CO_2 consumed by chemicals (kgCO2/kg)

Each used chemical should calculate its CO_2 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 [12].

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.

RESULTS

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 modeling 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 the 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 (Figure 1,2).

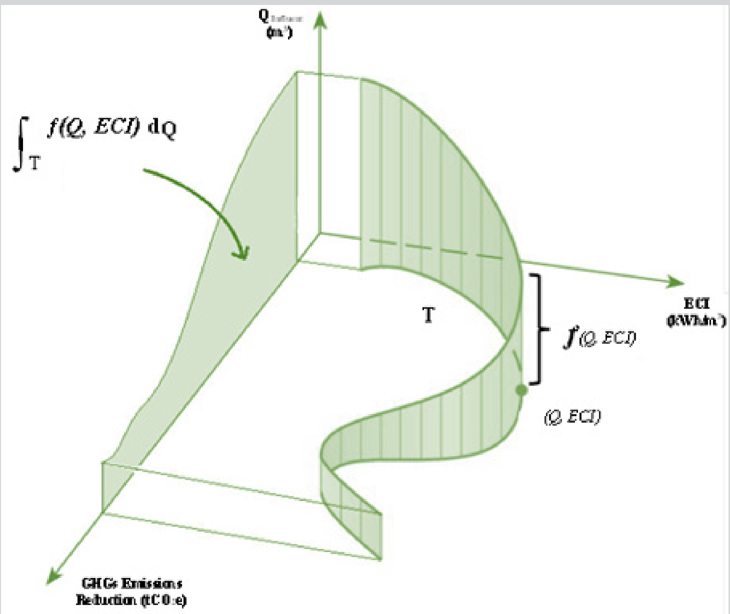

Figure 1: GHGs Emissions Reduction (tCO_2e).

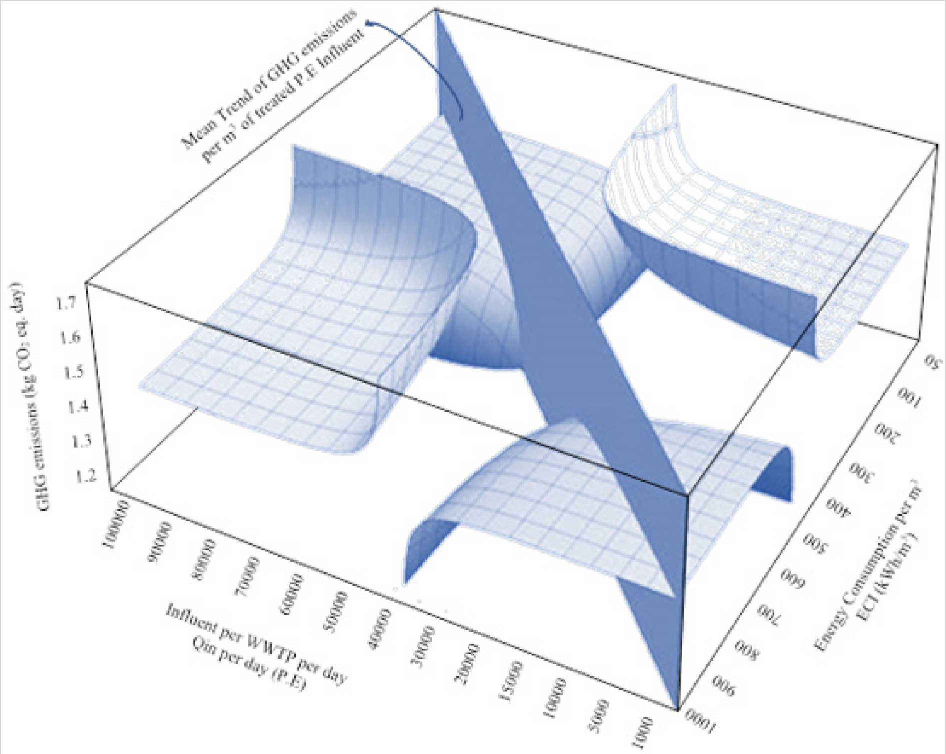

Figure 2: Final Model defining GHGs Emissions *vs.* Q & ECI.

FURTHER IMPROVEMENTS

The set of Algorithms ruling GHGs emissions during all treatment phases is translated into Bridge Models to generate the final model. The final model gathered all bridge models into Loophole Basis Control to assess all relevant projects via Software Interface. The 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 the 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 in 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 a larger scale, database upscaling, IT & WWT mix of knowledge challenge integrating core algorithms with fastest response, central computed connectivity to the electrical grid, sewer mains database incorporation, widening the application to more WWT typologies, and commercial enhancement to the interface.

CONCLUSION

This literature is the output of a close follow-up of the 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 a 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 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 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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