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Eco-efficiency dependencies for Wastewater Treatment Plant operation

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Abstract:
The operation of wastewater treatment plants (WWTP) faces numerous challenges. These facilities must guarantee effluent quality requirements addressing also economic and environmental issues in the presence of variable influent conditions. This work presents a comprehensive analysis of the influence of climate and meteorological conditions into the eco-efficiency aspects of control/operational strategies applied in WWTPs. The main novelty of this work is the consideration of dynamic environmental performance in the assessment method, which allows to identify the impact on eco-efficiency of the eventual and seasonal variations of temperature and precipitations. Different operation scenarios, with different wastewater temperature profiles and precipitation levels are defined, and eco-efficiency is evaluated in terms of emissions to water and energy consumption. Annual and monthly performance indicators are computed to provide a general view of plant behaviour in the different conditions. The Benchmark Simulation Model (BSM2) has been selected as a reference WWTP model. The analysis is performed from a plant-wide perspective, since the effects on different units of the plant are considered. The analysis makes possible to identify the operational issues and control problems that should be tackled to address environmental impacts as eutrophication and global warming potential, resulting in an improvement of WWTP eco-efficiency.

Keywords:
Wastewater treatment plants, eco-efficiency, sustainability, process control.

1. Introduction

The operation of wastewater treatment plants (WWTP) faces numerous challenges. These facilities must guarantee the imposed effluent quality standards, while attempting to address economic issues and environmental impact of the operation. These three aspects: emissions to water, environmental impact and economics have to be considered in a sustainability framework. In this study a comprehensive analysis of the influence of climate and meteorological conditions into the eco-efficiency aspects of control/operational strategies is performed.

The attainment of eco-efficiency targets when running WWTPs is a complex task because it includes the evaluation of environmental and economic performance indicators which are usually in conflict [1-3]. Then, a holistic viewpoint is necessary [4, 5] in the search for sustainable solutions for WWTP operation. Several performance indicators and assessment criteria for the evaluation of the eco-efficiency of WWTPs are available in the literature [1-5]. Among the different environmental performance indicators, measurements and criteria of a standardized procedure as the Life Cycle Assessment (LCA) are particularly interesting [1].

The variability of the characteristics of the incoming wastewater is one of the main issues that affect the operation of WWTPs. The influent flowrate and pollutants load are affected by different factors such as population activities, precipitations, sewer management, and industrial discharges [6]. Furthermore, wastewater temperature, that depends on ambient temperature and hot water discharges, is a relevant parameter [7-9] with a significant influence on biological processes kinetics, oxygen transfer processes and heating requirements of some WWTP processes. Therefore, WWTP operation should be accommodated to deal with the eco-efficiency, depending on the influent characteristics, while maintaining quality/cost aspects.

This study aims to determine the influence of climatological and meteorological conditions on treatment effectiveness and energy consumption in a conventional WWTP. The analysis is performed from a plant-wide perspective, since the effects on different units of the plant are considered. Some typical performance indicators [5, 10-12] and complementary efficiency indexes are selected to evaluate the effect of precipitations and temperature variations on the throughput of the WWTP. Dynamic evaluation of WWTP of performance [13] considering monthly operational windows for different weather scenarios is proposed to observe the influence of different operating conditions (and therefore costs) on the eco-efficiency of the operation. The Benchmark Simulation Model (BSM2) [10-12] has been selected as a reference WWTP model to drive the

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study. The main idea is to provide an assessment tool that facilitates the integration of meteorological insights in the formulation of the WWTP operation strategy.

The remainder of this paper is organized as follows. The BSM2 simulation platform, its control system and the eco-efficiency indicators are described in section 2. Section 3 introduces the methodology for the eco-efficiency assessment under different meteorological conditions. The results of the simulations of BSM2 plant under different meteorological conditions and the analysis of performance are presented in section 4. Conclusions are presented in section 4.

2. Process and control system

The BSM2 simulation platform is selected to describe the behaviour of a conventional WWTP with activated sludge biological treatment and anaerobic digestion. This is a widely recognized simulation platform designed as a benchmark to test control strategies applied to wastewater treatment facilities from a plantwide perspective [10-12]. The BSM2 version used in this work [12] represents only nitrogen removal processes. The phosphorous removal processes are not considered.

The influent data available in the BSM2 platform is obtained from influent generation models [6] that contemplates temperature, influent flow and pollutants concentration variations characteristic of a WWTP in the Northern Europe region. The analysis presented in this paper concentrates on the effect generated by temperature variations and precipitations.

2.1. Process description

The BSM2 plant model, the simulation platform and the evaluation protocol are described in [10-12]. BSM2 layout includes primary clarification and activated sludge process units in the water line, and anaerobic digestion, thickening, dewatering units and a storage tank in the sludge line (Fig.1). The influent model is described in [6], temperature variation is represented using a combination of sine functions that represents daily and seasonal variations, and load data represents influent flow and pollutants concentration variations associated with population activities, industrial activities, sewer effects and rain effects. Table 1 summarizes characteristic influent parameters.

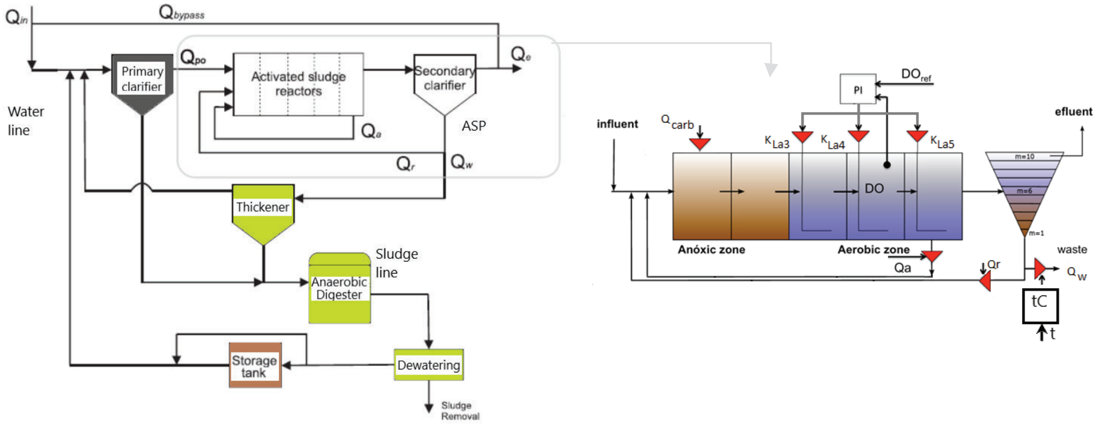

Figure. 1. BSM2 simulation platform layout and default control strategy

Table 1. Characteristic values of the significant variables of the influent profile

Variable	Average	Maximum	Minimum
T (ºC)	15	20.5	9.5
Q_{in} (m^3/d)	20648	85841	5146
N_{tot} influent (gN/m^3)	55.2	114.2	7.7
COD influent ($gCOD/m^3$)	592.2	1213.0	36.5

BSM2 activated sludge process (ASP) [10-12] is described here to facilitate comprehension of the paper. There are five bioreactors, denitrification process occurs first in two anoxic and perfectly mixed reactors. External carbon dosage (Q_{carb}) is required to keep denitrification, and internal recirculation (Q_a) is used to transfer nitrates from aerobic reactors. The 3rd to 5th reactors are aerobic to promote nitrification process. Oxygen is provided by an aeration system and the oxygen transfer is represented by oxygen transfer coefficients: KLa3, KLa4, Kla5 of each aerobic reactor. A settler separates the clean water (Q_e) that is discharged, and the sludge,

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that is divided: wastage flow (Q_w) is fed to the sludge line thickener, and external recycle flow Q_r returns to the head of ASP.

The anaerobic digester produces biogas and stabilizes the sludge. An operation temperature of 35ºC is necessary, then BSM2 considers a micro gas turbine to produce the heat required by the digester [12] and immediate electricity. The energy content of biogas is estimated as 13.89kWh/kgCH_4, a biogas to electricity efficiency of 43% and a biogas to heat efficiency of 50% is considered in BSM2 performance evaluation.

2.2. Control strategy

The predetermined control strategy provided with the BSM2 platform [10-12] is employed for all the case studies presented in this paper. It consists on DO control in the 4th reactor and timer-based control of Q_w. In the aerobic reactors, the levels of dissolved oxygen (DO) should be between 1 to 2 gCOD/m^3 to promote nitrification. Then, BSM2 applies a control system for the regulation of DO in the 4th reactor manipulating the oxygen transfer coefficient of the fourth reactor (KLa4). A PID controller is implemented in the proposed control loop, the tuning parameters can be found in [13]. The coefficients KLa3 and KLa5 depends on KLa4, with proportional gains of 1 and 0.5, respectively. The DO concentration in the 3rd and 5th reactor is affected by control actions applied in the fourth reactor.

Sludge purge flow (Q_w) affects the sludge age or solids retention time (SRT). In the BSM2 platform a timer-based control of Q_w is applied. If the wastewater temperature is below 15ºC (colder season) wastage flow (Q_w) is set to 300 m^3/d, else Q_w is set to 450 m^3/d.

2.3. Eco-efficiency indicators

The eco-efficiency assessment of WWTPs includes the evaluation of environmental and economic performance indicators which are usually in conflict [1-3], then, the search for sustainable solutions for the operation of these facilities results in an interesting multi-objective problem. Several performance indicators and assessment criteria for the evaluation of the eco-efficiency of WWTPs are available in the literature [1-3]. The consideration of measurements and criteria of a standardized procedure as the Life Cycle Assessment (LCA) is recommended, especially, the metrics in the impact categories of Eutrophication Potential and Global Warming Potential [1] which are important issues for these facilities. The Eutrophication Potential is associated with the emissions to water, and Global Warming Potential is associated with the energy consumption and the corresponding indirect emissions to air in the energy sources.

BSM2 platform provides a systematic evaluation protocol of plant performance under the different control strategies tested in the plant. Relevant variables such as the load and concentration of pollutants in the influent and the effluent, production of biogas and sludge are computed for a given evaluation period, as well as indicators of the suitability of the WWTP operation, as influent and effluent quality, violations of the effluent requirements, energy consumption and operation costs.

In this work, some of the performance indicators proposed in BSM2 platform are used to evaluate the environmental performance of the WWTP. The selected indicators are focused on the level of pollutants in the influent and the effluent, the use of energy and production of biogas in the plant, and in the operation costs. A general description of the indicators is presented below, a detailed description including equations can be found in [5,12].

2.3.1. Environmental indicators associated with emissions to water

- Effluent Quality Index, EQI (kg/d): it is a measure of the total pollution load of the plant discharge for a given operation period (i.e.one year). It includes the following measurements of pollutants in the effluent: total Nitrogen (N_{tot}), ammonium (S_{NH}), nitrates (S_{NO}), total Chemical Oxygen Demand (COD), total Suspended Solids (TSS) and Biological Oxygen Demand (BOD5) [5, 12].
- Influent Quality Index, IQI (kg/d): it is a measure of the total pollution load of the influent for a given operation period (i.e.one year). It includes N_{tot}, S_{NH}, S_{NO}, COD, TSS and BOD5 load in the influent [5, 12].
- Violations of effluent requirements. Desirable limits of pollutants in the effluent (Total nitrogen, ammonium concentration, total Chemical Oxygen Demand (COD) and total suspended solids (TSS)) are given in BSM2 platform [1-3]: $N_{tot} < 18$ gN/m^3, $S_{NH} < 4$ gN/m^3, COD <100 gCOD/m^3, TSS<30 g/m^3.These values are in concordance with current effluent requirements in European countries. Deviation of the levels of pollutants in the effluent from desired limits are quantified in terms of number of events, extension of time of the infringements (absolute and relative), and magnitude of the violation [5, 12].

2.3.2. Environmental indicators associated with energy consumption

- Pumping energy, PE (kWh/d): it is computed considering the pumps available on each unit: the internal recycle flow Q_a, the external recirculation flow Q_r, the wastage flow Q_w, the primary clarifier bottom flow, the thickener feed flow and the dewatering unit bottom flow [5, 12].

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- Aeration energy, AE (kWh/d): it depends on aeration system characteristics: type of diffuser, bubble size, depth of submersion. It is computed from oxygen transfer coefficient on each reactor and the volume of each reactor for Degrémont DP230 porous disks at an immersion depth of 4 m [5, 12].
- Mixing energy, ME (kWh/d): it is computed for activated sludge reactors if KLa<20 d^{-1} (ME_{AS}) and anaerobic digester (ME_{AD}), considering the volume of each reactor and digester volume, respectively [5, 12].
- Heating energy, HE (kWh/d) and heating energy net (HE_{net}): HE is the energy necessary to heat the sludge to the operation temperature required in the anaerobic digester, and HE_{net} is zero if methane produced in anaerobic digester (AD) covers its heating requirements, otherwise, HE_{net}=HE-7MET_{prod} [5, 12], it is computed considering that energy content of biogas is 13.89 kWh/kgCH_4 and biogas to heat efficiency is 50% [10]. MET_{prod} (kg/d) is the amount of biogas produced in AD.
- Electricity from biogas (EB, kWh/d): biogas is used in BSM2 to heat AD and to produce electricity simultaneously with an efficiency of 43%, then electricity from biogas is computed as 6MET_{prod} [10].

2.3.3. Economic indicators

- Operational Cost Index (OCI): it is defined in BSM2 as the net energy costs, the sludge production for disposal (SP) costs and external carbon addition (EC) costs [5, 12].

$$OCI=AE+PE+3SP+3EC-6MET_{prod}+HE_{net} \quad (1)$$

2.3.4. Efficiency indicators

Efficiency indices formulated as the ratio between interesting indicators are considered [10, 11].

The energy efficiency (EE), defined here as the ratio between pollution removed by BSM2 plant in kg and the energy consumed to achieve such objective (kWh):

$$EE=\frac{IQI-EQI}{Electricity}\ (kg/kWh) \quad (2)$$

This performance indicator has been used in previous works [4-5] however, interpretation of the evolution of the index should be cautious. Increments of the index are supposed to indicate efficiency improvement, but in some cases the index increases due to limitations of the control system that affect the energy use, then the index increases, but elimination of pollution is incomplete.

The treatment efficiency (TE) that is the ratio between the load of pollutants removed and the load of pollutants in the influent:

$$TE=\frac{IQI-EQI}{IQI} \quad (3)$$

The heating methane harnessing (HMH) that is the ratio between available heating energy from methane 7MET_{prod} and anaerobic digester heating requirements:

$$HMH=\frac{7MET_{prod}}{HE} \quad (4)$$

The electrical methane harnessing that is the ratio between the electrical energy obtained from methane and the electricity requirements of ASP (E_{ASP}):

$$E_{ASP}=PE+AE+ME_{AS}\ (kW) \quad (5)$$

$$EMH=\frac{6MET_{prod}}{E_{ASP}} \quad (6)$$

3. Description of eco-efficiency assessment procedure under different meteorological conditions

Four scenarios characterised by different influent conditions have been defined to evaluate the influence of climate and meteorological conditions on treatment effectiveness and energy consumption in BSM2 plant. Then, fifth case studies are considered including the default BSM2 scenario. The predeterminate BSM2 control strategy described in section 2.2 is applied in all cases.

- Scenario 1. Default. The BSM2 influent characteristics as described in table 1.
- Scenario 2. Wider temperature profile variation (W. T.). Mean temperature: 15ºC, minimum temperature: 5ºC and maximum temperature: 25ºC.
- Scenario 3. Higher temperature profile (H.T.). Mean temperature: 19ºC, minimum temperature: 10ºC and maximum temperature: 27ºC.

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- Scenario 4. Rainy year (R.Y.). The BSM2 influent data is modified copying and inserting data corresponding to rain events in the dry periods of the default influent profile.
- Scenario 5. Dry year (D.Y.). The BSM2 influent data is modified copying and inserting data corresponding to dry periods events in the rainy periods of the default influent profile.

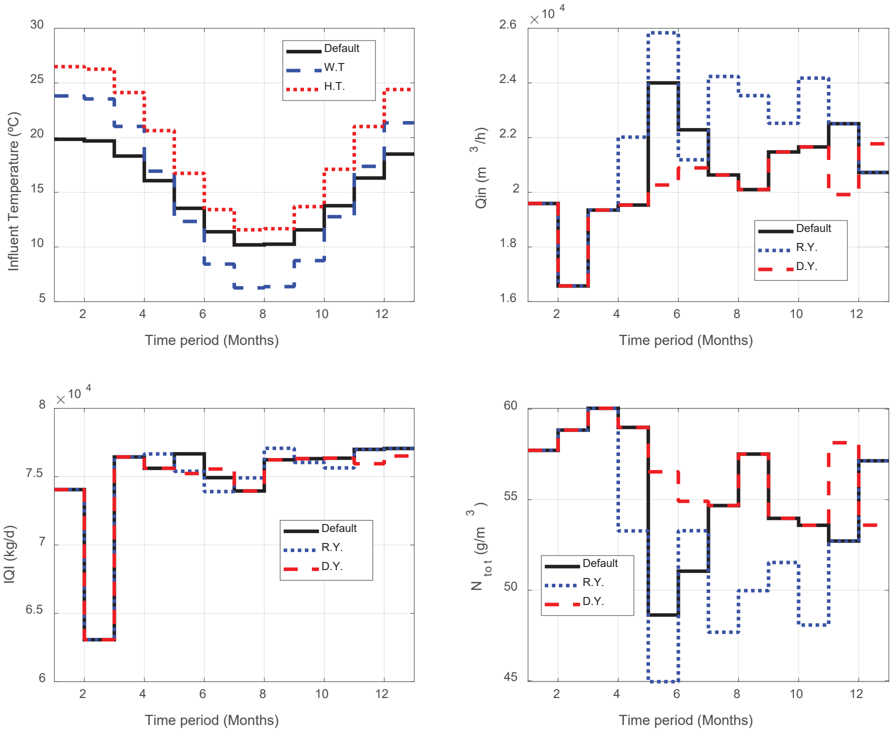

Figure. 2. Temperature and influent flow influent profiles for the different scenarios proposed to study the impact of meteorological conditions on WWTP performance.

An evaluation period of one year is recommended in the BSM2 protocol, the evaluation period starts the 1rst of July. A sample time of 15min is set in BSM2 platform, however monthly temporal windows are used here, to show the evolution of relevant variables. The monthly average profile of influent temperature and flowrate, Influent Quality (IQI) and total Nitrogen (N_{tot}) for the different scenarios is presented in Fig. 2.

The use of monthly windows facilitates the observation of seasonal changes of climate and meteorological conditions. In figure 2, in the representation of influent temperature, it is observed a step descend of temperature from summer season (1rst of July in the northern hemisphere) to winter (months 6 to 9) and the return to warmer periods at the end of the year. This trend is maintained in W.T. and H.T. scenarios within their corresponding range of variation. Regarding the influent flow, the first two months (July and August) are equal in all scenarios (dry weather and reduced influent flow due to holiday period), but average influent flow increases for precipitations, almost in all months in the R.Y. scenario, and decreases in winter and the beginning of summer in the D.Y. scenario. Precipitations affect the load of pollutants in the effluent as observed in IQI and N_{tot} profiles, N_{tot} concentration diminish in the rainy periods. Temperature variations do not affect influent pollutants concentration in BSM2 model.

4. Results

Simulations of plant behaviour, using the default BSM2 influent profile and the data adjusted according to the four scenarios describing temperature and precipitation changes, have been executed. Annual average performance and dynamic performance is evaluated and compared for the different scenarios. Control system performance is examined in the case that exhibits the worst behaviour associated with temperature and precipitations changes, to determine the possible drawbacks of the control system in these situations and to contemplate possible solutions.

4.1. Performance analysis in the different climate and meteorological scenarios

The annual average values of some performance indicators were computed to evaluate the overall performance in one year of operation. On the other hand, the dynamic evolution of relevant variables along the year is represented using monthly average values. Dynamic analysis makes possible to observe the seasonal effects of the influent variations in the operation period.

4.1.1. Comparison of the annual average performance

The annual average values of selected indicators of performance are presented in table 2. IQI is used as indicator of the load of pollutants in the influent to be removed. Environmental indicators associated with emissions to water are EQI, N_{tot} and S_{NH} violations and TE. S_{NH} violations are measured as the period of time out the desired limits. Energy consumption is measured with indicators of electricity use in ASP (E_{ASP}) and heating energy of AD (HE), and the ratios: EE, HMH and EMH, that measure of the amount of electricity used for removing pollution, and the usefulness of biogas to produce the heat and electricity required for the plant operation. Evaluation of emissions to water and energy consumption are associated with the eutrophication potential and global warming potential, that are environmental impacts in the recognized Life Cycle Assessment. OCI indicates the overall operation costs.

According to annual average values presented in Table 1, in H.T. scenario the operation at higher temperatures is favourable for environmental performance. Heating efficiency (HMH, HE) improves because the difference between the operation temperature of AD (35ºC) and the temperature of the sludge decreases. Electrical efficiency increases (EE), but consumption of electricity in ASP (E_{ASP}) is the highest compared with the other evaluated scenarios. Then, the EE index increases due to the improvement of pollutants removal.

On the other hand, W.T scenario exhibits the minimum consumption of electricity (E_{ASP}) but the worst electrical efficiency (EE), which indicates a lower removal of pollutants. This is corroborated by environmental indicators with extremely long violation periods of S_{NH} and N_{tot} limits. This W.T. scenario exhibits the minimum OCI among the different cases studies, probably because it presents the minimum consumption of electricity (E_{ASP}). Then, the conditions that provoke the minimum operations costs, produce the poorer environmental performance.

In the case of the Rainy Year scenario (R.Y.), the indicators of violations of the S_{NH} and N_{tot} requirements in the effluent are acceptable, but it exhibits the worst EQI values, with an increment of 7.3% with respect to the Default scenario. The temperature profile is equal for the Rainy and the Default scenarios, but a lower heating efficiency (HE) is observed in the former, indicating that the Rainy influent profile produces changes in the load of the anaerobic digester that increases the energy demand.

Table 2. Annual average values of selected performance indicators

	Default	W.T	H.T.	R.Y	D.Y.
IQI (kg/d)	74783	74783	74783	74747	74584
EQI (kg/d)	5576.7	5809.1	5218.2	5984.0	5375.0
OCI (EUR/d)	9450.0	9368.4	9650.3	9462.7	9437.2
Electricity ($E_{ASP,}$ kWh/d)	5017.1	4941.0	5126.3	5012.3	5009.2
Heating energy (HE, kWh/d)	4225.3	4260.7	3357.2	4437.4	4130.6
N_{tot} violation (time d)	4.28	7.48	1.19	5.56	4.23
S_{NH} violation (time d)	1.49	19.20	0.51	4.17	0.98
Treatment Efficiency (TE)	0.93	0.92	0.93	0.92	0.93
Electrical Efficiency (EE)	12.72	12.86	12.54	12.65	12.74
Heat from methane/HE (HMH)	1.80	1.79	2.17	1.69	1.84
Electricity from methane/ E_{ASP} (EMH)	0.24	0.24	0.28	0.22	0.25

4.1.2. Comparison of the dynamic performance of BSM2 in the proposed scenarios

The evolution of environmental indicators: Effluent Quality, N_{tot} concentration, S_{NH} concentration and Treatment Efficiency (TE) is presented in Fig. 3. In the figure, it is noticed a superior performance of the WWTP in the W.T. scenario compared with Default scenario in the warmer months (months: 1-4, 10-12). In the colder months (5-9), temperature of W.T scenario ranges between 13-6ºC (Fig. 2), while the minimum temperature of Default and H.T scenarios is 10ºC. In this colder period of operation, EQI, N_{tot} and S_{NH} for the W.T scenario experiment a significant increase with respect to H.T and Default conditions. Moreover, the treatment efficiency (TE) representation shows how pollutants removal efficacy decreases in the colder period in all the cases studied, but the reduction in the W.T. scenario is significant due to the lower temperatures. This behaviour cannot be appreciated in an analysis based on annual average indicators.

Regarding energy consumption and methane exploitation, Fig. 4 shows the dynamic evolution of the corresponding indicators. Electricity consumption in the ASP presents an important reduction in the colder month for the W.T. scenario, that is reflected as an increment of the EE and EMH ratios. In this case, larger values of these indicators could be interpreted as an improvement in the electrical efficiency of the plant, however, the observation of the environmental metrics leads to detect an operation problem in the colder period of W.T scenario. The HMH ratio, in the fourth subplot, is related with the use of methane to cover heating

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requirements of digester; it varies between scenarios in the periods of higher temperature, but attain similar values in the colder periods.

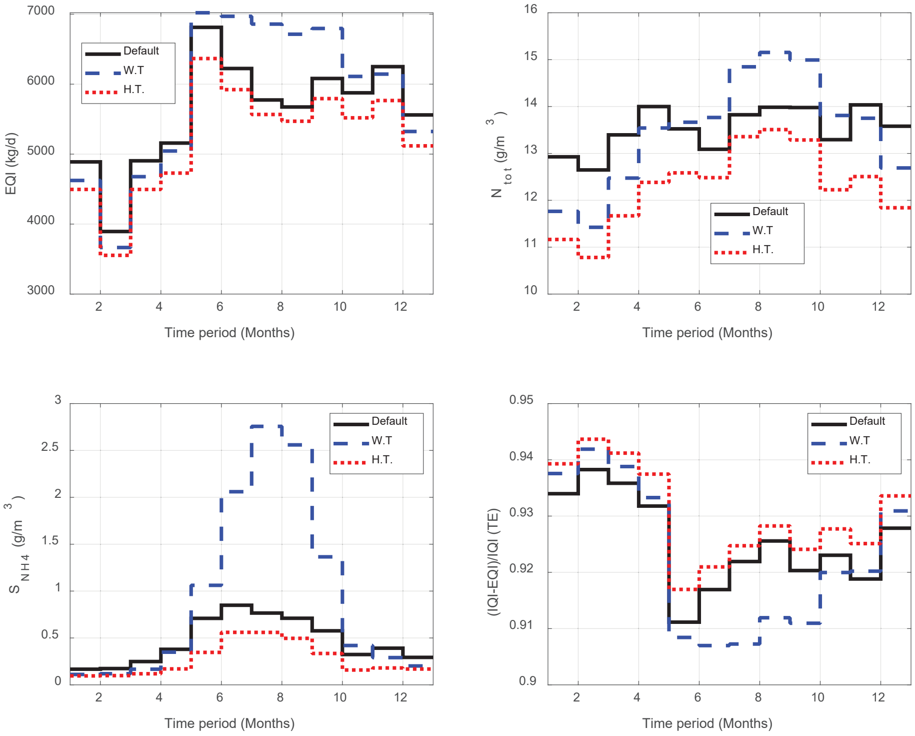

Figure. 3. Comparison of the effluent quality indicators for the operation scenarios focused on temperature variation (W.T., H.T.).

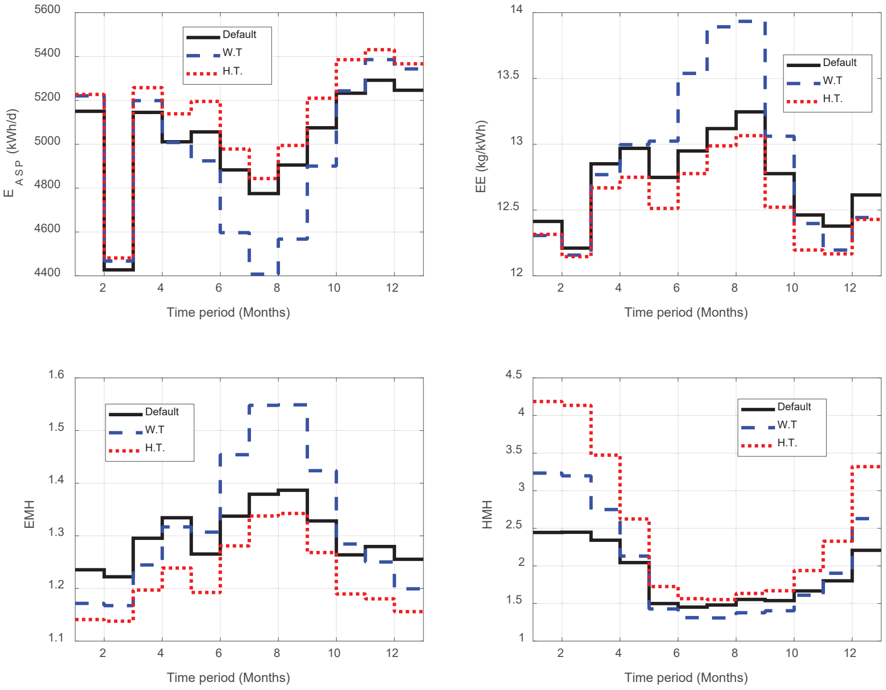

Figure. 4. Comparison of the energy efficiency indicators for the operation scenarios focused on temperature variation (W.T., H.T).

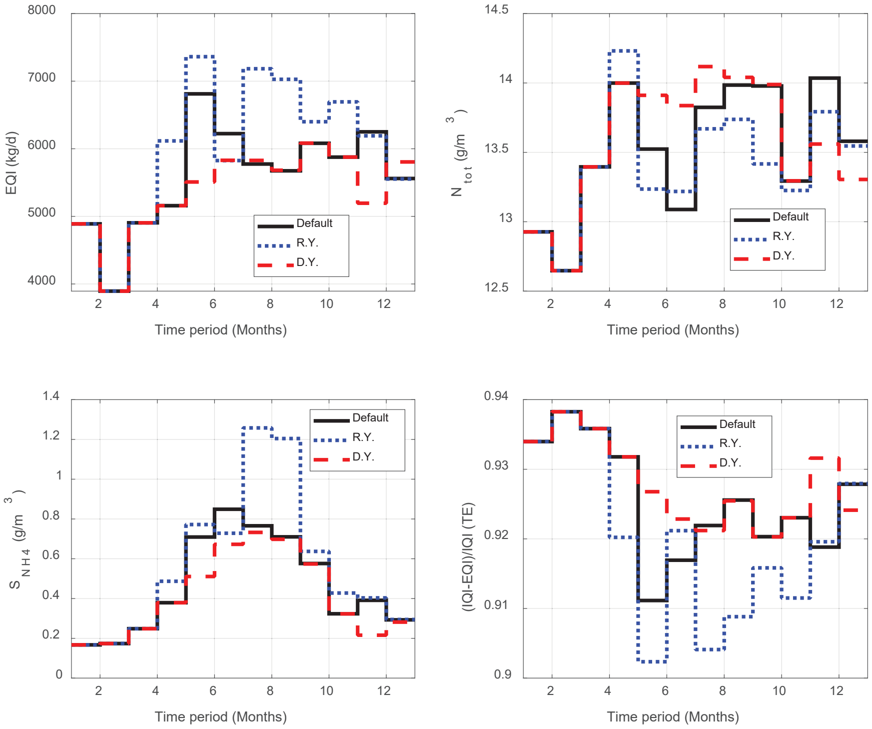

Figure. 5. Comparison of the effluent quality indicators for the operation scenarios focused on variation of precipitations (R.Y., D.Y.)

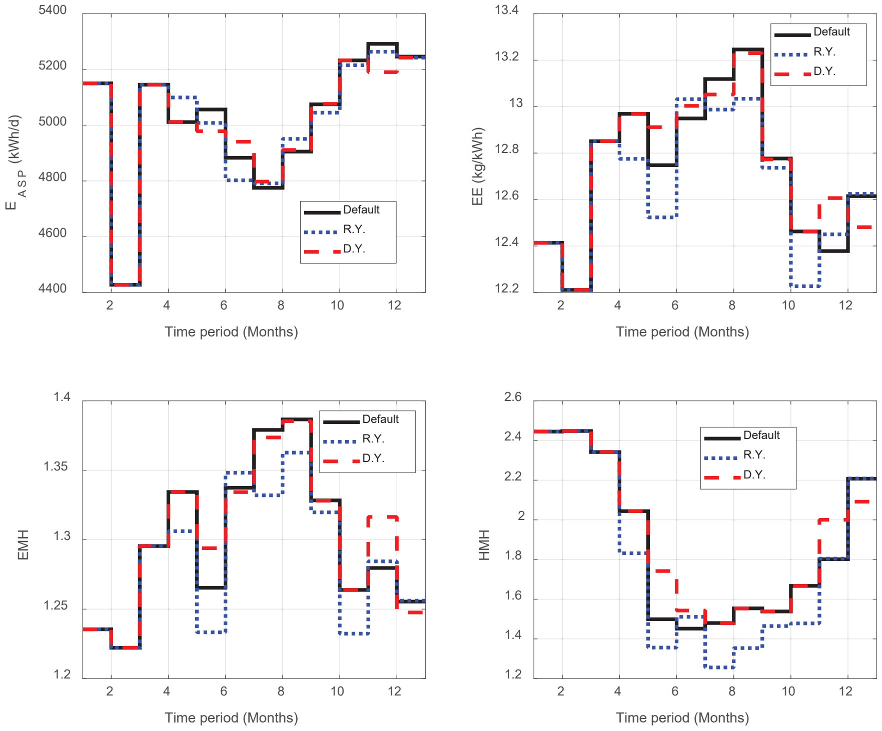

Figure. 6. Comparison of the energy efficiency indicators for the operation scenarios focused on variation of precipitations (R.Y., D.Y.).

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Figure 5 shows the comparison of the environmental performance indicators for the Default, Rainy Year (R.Y) and Dry Year (D.Y.) scenarios. It is observed that continuous precipitations affect negatively the indicators of effluent quality, specially S_{NH} concentration and the Treatment Efficiency (TE), although total nitrogen (N_{tot}) is slightly improved. The dynamic evolution of the energy consumption indicators is presented in Fig. 6. Electricity consumption is similar for the three scenarios and the effect of precipitations on the efficiency indicators is not clear. The effect of precipitations requires a detailed analysis considering separately the effect of precipitations and the effect of human activities. In this study both effects are combined in the R.Y. and D.Y. scenarios.

4.2. Comparison of control system performance in the W.T. and Default scenario.

Dynamic control system performance is studied to find the issues behind the atypical behaviour observed for the operation in the W.T. scenario in the colder periods. Figure 5 and Fig.6 shows the control variables: KLa4, SO_4, SO_3 and SO_5 in the Default and W.T. scenarios, respectively.

In both scenarios, good tracking of SO_4 reference is achieved with reasonable movements of the manipulated variable Kla4, there are no saturations nor instabilities. It is noticed that average KLa4 decreases between the days 275-300, that correspond with the second month (August), that is the period with the lower load (see Fig.2). In the colder months (days: 400-500d, months 6-9), a slight reduction of KLa4 is observed in the Default scenario, that is significant in the W. T. scenario (blue lines). This behavior explain the reduction of the energy consumption in the W.T. scenario. Furthermore, controlled SO_4 is not affected by KLa4 reduction in the colder days, and good reference tracking is maintained, but SO_3 and SO_5 concentrations are affected.SO_3 increases and SO_5 decreases in the colder period. This effect is amplified in the W.T: scenario, with SO_5 concentration approaching to the minimum allowed DO levels (see Fig. 6) This situation possibly produces the poor environmental performance in the W.T. scenario that reaches the lower temperatures.

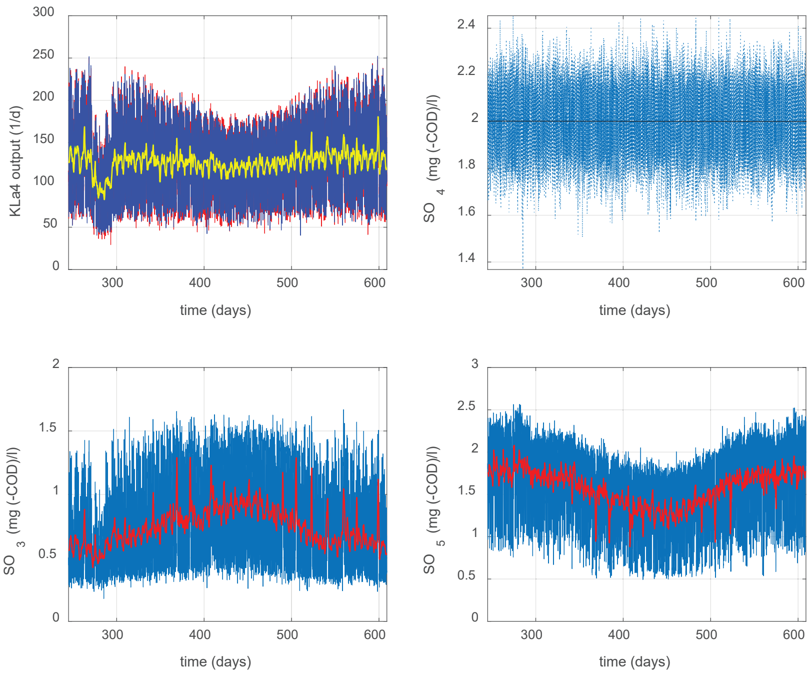

Figure. 5. Dynamic response of the plant in the default operation scenario. (SO_4 set-point: 2mgCOD/l. Yellow and red lines: filtered signals. Blue lines: samples obtained each 15min)

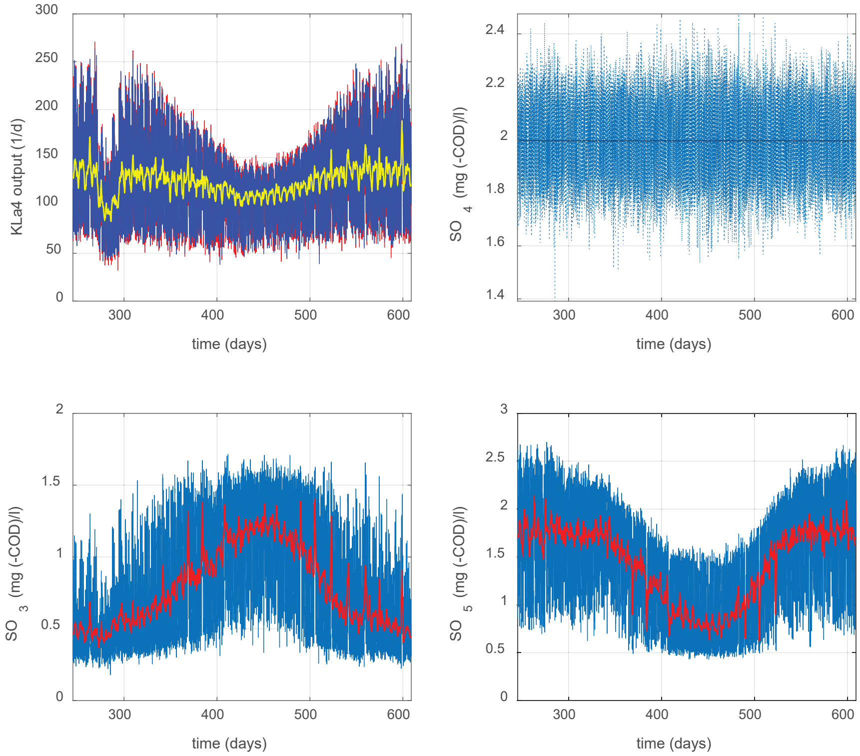

Figure. 6. Dynamic response of the plant in the W.T scenario (Wider temperature variation with respect to default scenario). (SO4 set-point: 2mgCOD/l. Yellow and red lines: filtered signals. Blue lines: samples obtained each 15min)

5. Conclusions

The evaluation of plant behaviour under different climate and meteorological scenarios has been carried out portraying annual performance, computing annual average eco-efficiency indicators, and dynamic performance, considering monthly operation windows. The analysis was performed from a plant-wide perspective, since the effects on different units of the plant were considered. The effect of weather conditions on environmental performance, in terms of emissions to water and energy consumption, an energy consumption was evaluated with appropriated indicators. The analysis showed that temperature variations affect significantly the environmental performance of the plant. Operational issues and control problems were detected in the periods of lower temperatures, that affect energy consumption. On the other hand, an influence of precipitations on indicators of emissions to water and energy consumption is observed, but deeper study of influent variations of concentration and influent flowrate is necessary. These problems should be tackled to address environmental impacts as eutrophication and global warming potential, save energy and reduce operation costs to make WWTP operation more eco-efficiency.

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Nomenclature

Temperature (ºC)	T	Activated Sludge Process	ASP
Influent flow (m^3/d)	Q_{in}	Anaerobic Digestion	AD
Total nitrogen (gN/m^3 o mgN/l)	N_{tot}	Wider Temperature	W.T.
Chemical oxygen demand (gCOD/m^3)	COD	Higher Temperature	H.T.
Influent Quality Index (kg/d)	IQI	Rainy year	R.Y.
Effluent Quality Index (kg/d)	EQI	Dry year	D.Y.
Operational Cost Index (EUR/d)	OCI	Oxygen Transfer Coefficient for i reactor	KLai
Electrical Efficiency (kg/kWh)	EE	Oxygen concentration reactor i	SO_i
Heat from methane (kWh/d)	HE	Dissolved Oxygen	DO
Treatment Efficiency (Dimensionless)	TE	Total Suspended Solids	TSS
Electricity from methane (Dimensionless)	EMH	Aeration Energy	AE
Heat from methane (Dimensionless)	HMH	Mixing Energy	ME
Electricity consumption in ASP (kWh/d)	E_{ASP}	Pumping Energy	PE

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