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Environmental evaluation of control strategies for wastewater treatment plant operation

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Abstract

In this paper an environmental analysis of different wastewater treatment plant (WWTP) control strategies is carried out. The BSM1 is taken as the benchmark scenario used to implement the control simulations. The LCA method allows to complement simulation results since the environmental consequences of the implemented control strategies can be evaluated from another perspective, not included in the BSM1 framework. The provided environmental indicators can be joined with the cost/performance ones provided by the BSM1 scenario. It is shown how to get an overall evaluation of the environmental effects by using a normalized graphical representation that can be easily used to compare control strategies from the environmental impact point of view.

Palabras clave: wastewater treatment plants, Life Cycle Analysis, Environmental impact

1 Introduction

In Europe, the implementation of the Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment, mandates new concepts in management and operation from the adaptation of existing plants, that lack robustness and flexibility, to adapt to the new requirements. In order to solve the main problems of wastewater management, researchers efforts have been focused, during last years, in objectives such as i) to improve the water quality by also minimizing the operational costs in order to achieve sustainable treatments and ii) to minimize the sludge production and increase its usability for energy recovering [8, 10, 26]. Automatic control has been used as a support to achieve the proposed objectives.

In the literature there are several papers working on modelling of WWTPs as [23, 24, 30, 31]. In this work the evaluation and comparison of the different control strategies is based on the Benchmark Simulation Model No.1 (BSM1), developed by the International Association on Water Pollution Research and Control [3, 1, 6]. This benchmark defines a plant layout, influent loads, test procedures and evaluation criteria. On this respect, WWTP operation is usually conducted on the basis of the usual cost/performance trade-off, measured in terms of the usual Operation Costs Index (OCI) and Effluent Quality Index (EQI). In fact this is the orientation of the usual WWTP control and operation studies, where effluent quality is one of the major concerns [12, 25]. Due to implementation of control the general performance of Wastewater Treatment Plants (WWTPs) has been improved, but the analysis from the environmental point of view has not been detailed sufficiently.

LCA is considered a convenient tool for the assessment the environmental performance of WWTPs [9, 22, 19]. The International Standard ISO14040 [15] defines LCA as a compilation and evaluation of the inputs, outputs and potential environmental impacts of a system throughout its life cycle, from the production of the raw materials to the disposal of the generated waste. The analysis is done by compiling first an inventory of the relevant inputs and outputs of the system followed by an evaluation of the potential impacts associated with these inputs and outputs. Afterwards an interpretation of the results of the inventory analysis and impact assessments steps in relation to the objectives of the study [20] is conducted. Some works are focused on carbon footprint, see [4] for example, as an attempt to characterize environmental impact. However it is the authors opinion that LCA provides a wider and more complete perspective.

The combination of control simulations and LCA to evaluate the environmental plant's performance is seen as an important contribution. The fact of assessing the application of control strategies in WWTPs from the environmental point of view using LCA method adds a kind of natural complement to the WWTPs evaluation. Also, it allows stakeholders to take decisions regarding the environmental consequences of the application of the control strategies on the basis of the potential impact results because complementary information is given by this combination. This is the main motivation of the formulation of the conducted mul-

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ticriteria analysis. Because of that, in this work, the environmental profile of ten control strategies implemented in the BSM1 is analyzed by using the LCA methodology.

The article has been organized as follows: First the BSM1 is presented in section 2. Section 3 follows by presenting the different control strategies to be considered in the study. Section 4 presents the LCA methodology whereas results and comparison between control strategies are conducted in section 5.

2 Benchmark Scenario: The BSM1

This section provides a description of the working scenario provided by the BSM1 [2]. This is a simulation environment defining a plant layout, a simulation model, influent loads, test procedures and evaluation criteria. The plant layout is composed of 5 activated sludge reactors in series followed by a clarifier. The first two reactors are non aerated but fully mixed tanks with a total volume of 2000 m^3. They are followed by 3 aerobic tanks with a total volume of 3999 m^3 and the clarifier has a total volume of 6000 m^3 (figure 1). The plant has been designed to treat an average influent dry-weather flow rate of 18446 m^3d^{-1} and an average biodegradable chemical oxygen demand (COD) in the influent of 300 gm^{-3}. Influent data include 3 dynamic files used for testing dry, rain and storm conditions. The hydraulic retention time is of 14.4 hrs and the wastage flow rate (Q_w) is of 385 m^3d^{-1} [2]. For modeling the nitrogen and carbon removal processes that take place in the sludge reactors the BSM1 platform uses the Activated Sludge Model No.1 (ASM1) [14]. The clarifier is modeled as a non-reactive ten layers unit with a double exponential settling velocity as is described in [28].

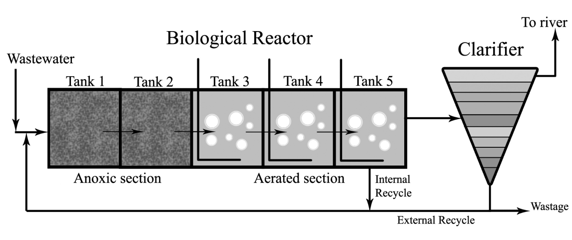

Figure 1: BSM1 plant layout

2.1 Simulation procedure

A simulation protocol is established to ensure that results are got under the same conditions and can be compared. So first a 150 days period of stabilization in closed-loop using constant influent data has to be completed to drive the system to a steady-state. This ensures a consistent starting point and should eliminate the influence of starting conditions on the generated dynamic output. Then, it continues by applying 14 days of dry influent data as a dynamic input. After this, the state variable values are saved as the starting point to evaluate the dynamic response of the plant to each dynamic influent file. From the achieved state, the dynamic influent file to be tested is simulated during 14 days of further simulation but in separate studies. Only the results of the last seven days are considered for the performance assessment.

2.2 Performance assessment

In order to compare the different control strategies, different criteria are defined. The performance assessment is made at two levels. The first level concerns the control. Basically, this serves as a proof that the proposed control strategy has been applied properly. The second level provides measures for the effect of the control strategy on plant performance. It includes Effluent Quality Index (EQI) and Overall Cost Index (OCI). They quantify the pollution in discharged water and the cost of operating the plant respectively. In this work we concentrate on these second level indexes as they are plant wide defined, while the first level ones apply to each specific control loop. EQI is defined to evaluate the quality of the effluent. It is related with the fines to be paid due to the discharge of pollution. EQI is averaged over a 7 days observation period and it is calculated weighting the different compounds of the effluent loads, whereas the OCI introduces considerations on the economic cost of plant operation.

As in this work we will concentrate just on the environmental impact, no detailed description of such indices computation will be provided. For a more detailed description one can see, for example, [25].

3 Implemented Control strategies

PI and PID (Proportional Integral Derivative) controllers are by far the most used controllers in industry. The simplicity and good trade off between performance and robustness for PI controllers make them the most preferable option among practitioners [29]. The considered control strategies are presented below. They are based on feedback loops defined in terms of Proportional Integral (PI) controllers.

The operation of a WWTP is based on the implementation of control loops that allow to manipulate different variables of the system. The main variables to be controlled in this plant are the dissolved oxygen in the aerated tanks, the ammonia in the effluent, the nitrates in the anoxic section and the suspended solids in the effluent. These control loops can be found in the literature on WWTP control and are defined in order to achieve specific purposes on determined compound concentrations. In what follows, each one of these, PI based, basic feedback control loops is presented showing the primary reference where it was originally defined. Starting from these considerations, a set of five basic control strategies (S1 to S5) have been implemented (figure 2).

- **S1**: Control of the dissolved oxygen concentration in the aerobic reactors ($D_{O3,4,5}$) by manipulating its respective oxygen transfer coefficients ($K_La_{3,4,5}$) [2] (figure 2a).
- **S2**: Control of the ammonia in the last aerobic tank (S_{NH5}) by manipulating the oxygen set points (D_{Oset}) in all the aerobic tanks [17] (figure 2b).
- **S3**: Control of the nitrate concentration in the last anoxic tank (S_{NO2}) by manipulating the internal recycle flow rate (Q_a) [6] (figure 2c).
- **S4**: Control of the nitrate concentration in the last anoxic tank (S_{NO2}) by manipulating the carbon source flow rate (Q_{Carb1}) into the first anoxic tank [32] (figure 2d).
- **S5**: Control of the total suspended solids concentration (T_{SS5}) in the last aerobic tank by manipulating the wastage sludge flow rate (Q_w) [16] (figure 2e).

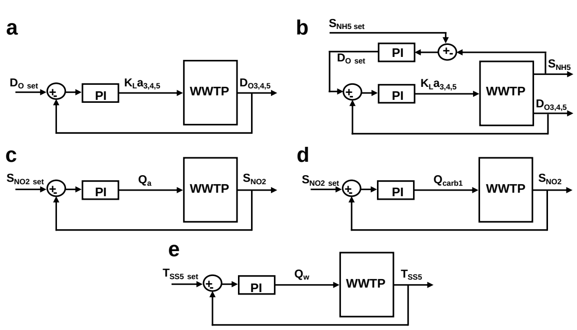

Figure 2: Basic control strategies: (a) **S1**: Oxygen PI controller, (b) **S2**: Ammonia PI controller, (c) **S3**: Nitrate PI controller (handling Q_a), (d) **S4**: Nitrate PI controller (handling Q_{carb1}), (e) **S5**: Total Suspended Solids PI controller

From the basic operation strategies S1 to S5, another five composite ones have been implemented by choosing the control of S_{NH5} strategy (S2) in order to be combined with the control of S_{NO2} by manipulating Q_a (S3), control of S_{NO2} by manipulating Q_{Carb1} (S4) and control of T_{SS5} (S5) strategies. Then, the control strategies S6 to S10 are defined as:

- **S6**: Control of S_{NH5} (S2) + control of S_{NO2} by manipulating Q_a (S3).
- **S7**: Control of S_{NH5} (S2) + control of S_{NO2} by manipulating Q_{Carb1} (S4).
- **S8**: Control of S_{NH5} (S2) + control of T_{SS5} (S5).
- **S9**: Control of S_{NH5} (S2) + control of S_{NO2} by manipulating Q_{Carb1} (S4) + control of T_{SS5} (S5).
- **S10**: Control of S_{NH5} (S2) + control of S_{NO2} by manipulating Q_a (S3) + control of T_{SS5} (S5).

4 Analysis of WWTP operation by means of LCA

As stated, the main purpose of this study is to complement the usual BSM1 assessment indexes with an environmental impact perspective provided by the Life Cycle Assessment (LCA) technique. LCA, defined by International standard ISO14040 (ISO 14040, 2006) as a technique to assess the potential impacts associated with a product or process during the whole of its life cycle, involves the following steps: definition of the goal and scope, inventory analysis and impact assessment and their corresponding interpretation. In what follows, these three basic components of LCA within the scenario defined by the BSM2 are defined and specified.

4.1 Definition of the goal and scope

The definition of the goal and scope should correspond with the LCA study application and should be described clearly. The goal defines the objective and the justification of the LCA study. The scope considers relevant aspects of the study such as the functional unit used in energy and mass balances, system boundaries, the type and extension of impact assessment, the data necessary to characterize the system, the public to whom is directed and the limitations of the study [21].

The *main objective* of this LCA study is to analyze the environmental profile of the ten control strategies implemented in the BSM1 plant and to assess resulting potential impacts between the control strategies and the impact categories selected.

As the main function of WWTPs is to treat the influent to reduce organic, nutrients and suspended solids loads in order to achieve satisfactory values before the discharge of the effluent into the receiving waters. Thus, referring this unit to the average influent dry-weather flow rate of the BSM1 (18446 m^3d^{-1}) and its corresponding loads, the treatment of 1 m^3d^{-1} of wastewater during 7 days (the evaluation time of the BSM1), has been selected as the *Functional Unit (FU)*. Therefore, the FU refers to both, amount of water and period of time this water is processed.

The *system boundaries* have been constrained just to consider the operational phase in the LCA carried out and they have been established from "gate to gate" of the BSM1 WWTP. The construction phase has been excluded from the system boundaries because the plant used is the same for all control strategies tested. But, the generation and transmission of the electricity used in the plant, the production of the chemicals used in the anoxic reactors to improve denitrification and the transportation of the generated sludge to its final destination have been included into the boundaries. The sludge is considered that is used in agriculture as a fertilizer, being this application one of the most common in Spain [22].

4.2 Inventory analysis

The inventory analysis step consists of data collection and analysis of the system under study in order to quantify the inputs and outputs. The inputs and outputs are related to the use of resources (energy and raw materials) and to the release of emissions to soil, water and air. The major part of data for this study was collected from the dynamic simulations performed using the BSM1. Table 1 shows the inventory parameters used in this LCA study for each one of the implemented control strategies related to the functional unit. However, some other part of the inventory data, that was not provided by the simulations, was collected from databases and literature. These data are:

- **Electricity and chemicals:** The electricity production data were taken from Ecoinvent Database [27] taking into account the Spanish energy production profile. In the case of the chemicals used in the BSM1 plant, the methanol has been selected as the external carbon source for enhancing the denitrification process.
- **Fertilizers avoided:** The application of sludge in agriculture reduces the use of chemical fertilizers. This results in benefits for the soil as long as the concentration of heavy metals in sludge is within the permitted limits. The most common chemical fertilizers used in Europe are the calcium ammonium nitrate (N-based) and the triple superphosphate (P-based). The substitutability was assumed as 6.93 kg of triple superphosphate and 39.6 kg of calcium ammonium nitrate per ton of sludge [22].
- **Heavy metals:** Heavy metals concentration depends mainly on the amount of industrial wastewater in the influent flow. As the BSM1 influent does not contains measures of these concentrations, an alternative source has been used: the study [7] realized in several European countries that summarizes the average of heavy metals concentrations that can be found in dehydrated sludge.
- **Methane and nitrogen emissions:** The emissions resulting from sludge application to agriculture was calculated as in [18].
- **Phosphorous:** ASM1 does not consider the phosphorus removal process. Nevertheless, the phosphorus in the effluent was calculated by subtracting the phosphorus concentration in the influent (166 kg P d^{-1}) [11] and the phosphorus concentration in the sludge, calculated as 0.04 kg P per kg of sludge.
- **Sludge transportation:** The transportation of sludge to the farms for agricultural purposes has been calculated by assuming that farms are located at an average of 50 km from the WWTP. Data for the calculation of the environmental loads caused by the sludge transportation in a 16 ton lorry has been taken from Ecoinvent Database [27].

4.3 Impact assessment

In this step of the LCA, the inputs and outputs of the inventory are analyzed and their respective potential contributions are cataloged in terms of several impact categories. The result of the Life Cycle Impact Assessment (LCIA) is an evaluation of the product life cycle, established by the relationships between the use of resources and the release of emissions, to their respective impacts [15].

In this study, the CML 2000 methodology, developed by the Institute of Environmental Sciences (CML) of Leiden University [13], has been used to analyze the operational impact of the implemented control strategies. This characterization model provides the characterization factors which quantify the environmental impacts of the released

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Table 1: Inventory data for the evaluated control strategies. All data has been normalized with respect to the chosen functional unit (the treatment of 1 m^3d^{-1} of wastewater during 7 days)

Strategies	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Inputs										
From background system										
Electricity (kWh)	0.21	0.22	0.31	0.31	0.31	0.22	0.24	0.22	0.24	0.22
Carbon source (kg)	0	0	0	0.08	0	0	0.06	0	0.06	0
Outputs										
Emissions to soil										
Sludge for disposal (kg)	0.12	0.12	0.12	0.15	0.12	0.12	0.14	0.12	0.15	0.12
Heavy metals in the sludge										
Cd (mg)	1.23	1.23	1.23	1.45	1.21	1.23	1.41	1.22	1.47	1.22
Cr (mg)	124	124	124	145	122	124	141	123	148	122
Cu (mg)	124	124	124	145	122	124	141	123	148	122
Hg (mg)	1.23	1.23	1.23	1.45	1.21	1.23	1.41	1.22	1.47	1.22
Ni (mg)	37.1	37.1	37.0	43.5	36.4	37.0	42.4	36.7	44.3	36.6
Pb (mg)	92.7	92.7	92.7	109	91.1	92.7	106	91.8	111	91.7
Zn (mg)	309	309	309	363	304	309	353	306	369	306
Emissions to water										
Total COD (g)	48.9	49.0	48.9	50.5	49.3	48.9	50.0	49.2	49.1	49.2
Total BOD (g)	2.79	2.79	2.78	3.14	2.80	2.79	3.12	2.81	3.02	2.81
NO_3 (g)	12.7	12.3	14.8	7.37	15.4	13.2	7.12	12.2	6.95	13.2
S_{NH} (g)	1.27	1.28	0.98	1.22	0.91	1.21	1.45	1.21	1.85	1.14
Total N (organic) (g)	2.01	2.01	1.99	2.14	2.03	2.01	2.12	2.02	2.08	2.02
Phosphorus (g)	4.06	4.06	4.07	3.20	4.15	4.07	3.35	4.11	3.10	4.12
Heavy metals in the effluent										
Cd (mg)	0.14	0.14	0.14	0.15	0.14	0.14	0.15	0.14	0.14	0.14
Cr (mg)	13.9	13.9	13.9	15.1	14.3	13.9	14.7	14.1	14.1	14.1
Cu (mg)	13.9	13.9	13.9	15.1	14.3	13.9	14.7	14.1	14.1	14.1
Hg (mg)	0.14	0.14	0.14	0.15	0.14	0.14	0.15	0.14	0.14	0.14
Ni (mg)	4.18	4.18	4.18	4.52	4.28	4.18	4.41	4.23	4.21	4.23
Pb (mg)	10.5	10.5	10.5	11.3	10.7	10.5	11.0	10.6	10.5	10.6
Zn (mg)	34.9	34.9	34.8	37.7	35.7	34.9	36.8	35.3	35.1	35.3
Emissions to air										
CH_4 (g)	0.62	0.62	0.62	0.72	0.60	0.62	0.71	0.61	0.74	0.61
N_2O (g)	0.06	0.06	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.06
NH_3 (g)	1.21	1.21	1.21	1.42	1.19	1.21	1.39	1.20	1.45	1.20

emissions in the corresponding impact categories. From an available wide set of impact categories, the following seven ones have been selected to perform this study taking into account that they are commonly used in wastewater LCA studies [8, 9, 22]. The selected impact categories, as described in Table 2, are: Acidification Potential (ADP), Global Warming Potential (GWP), Eutrophication Potential (EP), Terrestrial Ecotoxicity Potential (TAETP), Photochemical Oxidation (PHO), Depletion of Abiotic Resources (DAR) and Ozone Depletion Potential (ODP). Table 2 provides a short description and units of each one of the categories.

Table 2: Description of the impact categories used in the LCA [13]

Impact category	Units	Description
Acidification Potential (AP)	kg SO_2 eq.	It reflects the contribution of substances that produce H_2SO_4 when in contact with water. When these substances are present in the environment they produce acids rain, causing terrestrial and aquatic species degradation.
Global Warming Potential (GWP)	kg CO_2 eq.	It reflects the contribution of the various emissions to the increase in the effect of global warming. The most important substances are CO_2, CH_4, N_2O and the halogenated hydrocarbons.
Eutrophication Potential (EP)	kg PO_4^{-3} eq.	It reflects the contribution from the various emissions to the accumulation of nutrients in the environment. When nutrients accumulate in aquatic ecosystems, plant growth is increased, causing depletion of oxygen levels.
Terrestrial Ecotoxicity Potential (TAETP)	kg 1.4-DCB eq.	It reflects the contribution of substances that affect the humans health, flora and fauna. The most important are the heavy metals and radioactive substances.
Photochemical Oxidation (PHO)	kg formed ozone	This reflects the contribution from the various emissions to the formation of photo-oxidant substances (particularly ozone and peroxyacetyl nitrate) via the photochemical oxidation of volatile organic substances and carbon monoxide.
Depletion of Abiotic Resources (DAR)	kg antimony eq.	This reflects the contribution from the various emissions to the extraction of resources, considering their availability, energetic content, concentration and use velocity.
Ozone Depletion Potential (ODP)	kg CFC-11 eq.	This reflects the contribution from substances that cause the depletion of the ozone stratospheric layer. The most important substances are chlorated and bromated halocarbons, particularly trichlorofluoromethane (CFC-11, also known as freon-11).

5 Results and discussion

This section conducts the interpretation of the WWTP operation in terms of the indexes and impacts resulting from both the BSM1 scenario simulations and the application of the LCA method. LCA results are presented and analyzed.

From the environmental point of view, each one of the control strategies will have different repercussions that do not need to follow any cost or economical reason. What is desirable is to build up a figure of merit that captures the overall environmental behavior of a control strategy. In order to achieve this, first of all, each impact category has been normalized with respect to the control strategy that behaves worst (this is to say it generates the larges environmental impact). This way, all normalized impacts will have a value between 0 and 1. On that basis, a control strategy that has more impacts with values closer to 0 will behave better than another now with values closer to 1. These normalized values have been represented using a radar chart as it results very useful to display multivariate data in the form of a two-dimensional chart. Small values are closer to the origin whereas values that are at the boundaries of the chart represent the worst behavior. The radar chart for the evaluated control strategies can be seen in figure 3.

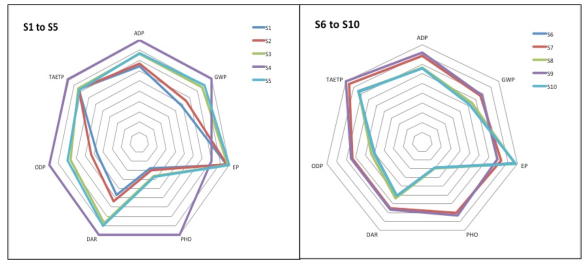

Figure 3: Environmental comparison of control strategies. Best results correspond to points closer to the origin.

Radar diagrams shown in figure 3 allow the environmental evaluation of control strategies, where they have been grouped as basic strategies (S1 to S5) and combined strategies (S6 to S10) for clarity of presentation. From the first group it is possible to identify S4 (S_{NO} control in unit 2 by manipulating Q_{carb}) as the worst strategy from the environmental point of view (even it belongs to G1 from the EQI/OCI perspective, offering best effluent quality). In the same figure, S1 (DO control in all aerobic reactors by manipulating $K_{L_{a3}}$, $K_{L_{a4}}$ and $K_{L_{a5}}$) provides a better behavior in all impact categories except in eutrophication (the corresponding polygon is contained in all the other strategies polygons).

Second figure draws two sets of strategies. S8 (combination of S2 and S5) and S10 (combination of S2, S3 and S5) with an overall better behavior in all impact categories except for EP. As it is just in one category that they fail to be better, we can take these two as providing better overall environmental behavior. In order to choose between S8 and S10, it is seen that S10 is slightly better than S8 in two categories and at the same level in the rest.

Therefore, the environmental analysis would suggest the use of S1 or S10. If now we proceed one step further with this environmental comparison and face S1 to S10 we can find a slight advantage for S1.

5.1 Featured WWTP operation analysis

As commented on the previous subsection, the LCA results provide S1 and S10 as the best ones from the environmental point of view, showing

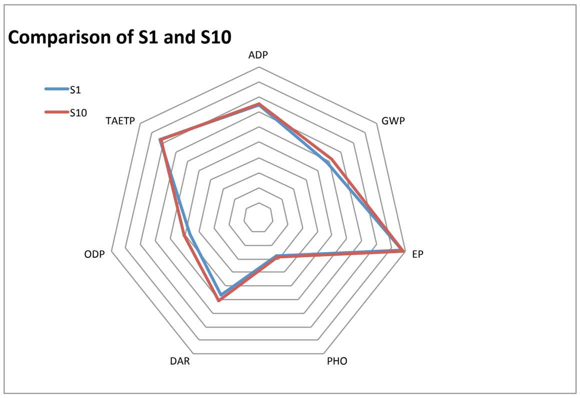

Figure 4: Environmental comparison of control strategies S1 (DO control in all aerobic reactors by manipulating $K_{L_{a3}}$, $K_{L_{a4}}$ and $K_{L_{a5}}$) and S10 (combination of S2, S3 and S5).

however quite similar overall evaluation. However, bearing in mind that S1 is the simplest control strategy, we could conclude that it is worth to use S1 for providing a reasonable cost/performance tradeoff and, at the same time, the best overall environmental behavior. This view puts on the table the question regarding the suitability of implementing the additional control loops present in S10 as when we evaluate the plant operation from a wide plant point of view, the benefits of such complex control scheme are not clear.

In order to introduce a different perspective, a previous study [5], suggests a possible grouping of control strategies according to the cost/quality tradeoff in three groups: G1(high effluent quality), G2(low cost) and G3(quality/cost tradeoff). That way, depending on the preferences on how to operate the plant a new dimension provided by the LCA may help to select the most appropriate control strategy within each group.

- Group G1: High effluent quality operation. For group G1, the analysis reinforces the fact of not choosing S4 (S_{NO} control in unit 2 by manipulating Q_{carb}). In fact this strategy is the one that represents a major investment and do not provide better effluent quality than S7 (combination of S2 and S4), or S9 (combination of S2, S4 and S5). In addition, both S7 and S9 are almost identical from the environment impact they generate. The only difference is that S9 does include T_{SS} control in addition to the control loops already present in S7. Therefore to keep S7 would be a very good option if the plant operation is for high effluent quality.

- Group G2: Low cost operation. For group G2, a wise selection is S3 (S_{NO} control in unit 2 by manipulating Q_a). From an environmental point of view is drastically better, except for TAETP, than S5 (T_{SS} control in unit 5 by manipulating Q_w). S3 also dominates S5 from a pareto perspective (this is to say it is better simultaneously in both objectives EQI and OCI), even slightly.

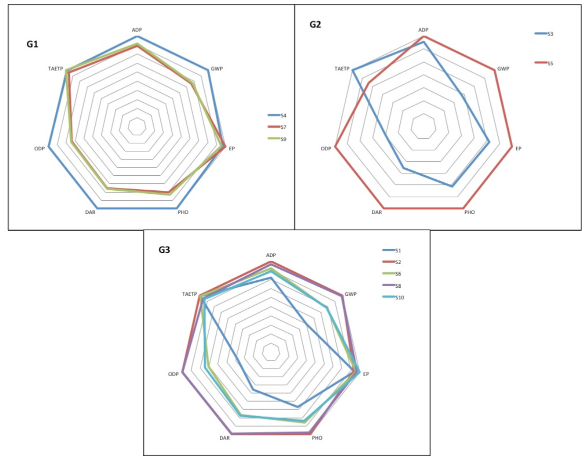

Figure 5: LCA results interpretation within each one of the three control strategies groups G1, G2 and G3.

- Group G3: Quality/Cost tradeoff operation. Regarding strategies of group G3, the decision is not clear if we just concentrate on the EQI/OCI tradeoff. There are five control strategies in this group providing similar results. Therefore, it results quite difficult to really choose one control strategy within the group. It is on this level of decision where the adding of a different criteria that complements the ones defined within the BSM1 benchmark helps to decide. If we can consider that from the cost/quality point of view the five control strategies are almost equal, its behavior may not be the same if we look at the environmental side. Figure 5 provides the radar chart for the strategies of group G3. It is clear that S1 (DO control in all aerobic reactors by manipulating $K_{L_{a3}}$, $K_{L_{a4}}$ and $K_{L_{a5}}$) provides a clear superior behavior regarding the environmental impact. Therefore it justifies the application of the most simple control strategy.

For each one of this three situations, the environmental considerations allowed us to discriminate one control strategy from the corresponding group. The selected strategy provides, in addition to the kind of operation associated to the group the most suitable operation from the environmental point of view.

6 Conclusions

This study has combined the Benchmark Simulation Model No.1 and the Life Cycle Assessment technique in order to evaluate different wastewater treatment plant control strategies from the environmental point of view.

A total of ten control strategies have been analyzed. Ranging from very simple to more complex ones the control strategies are implemented within the BSM1 scenario and simulation results used to evaluate them. LCA is applied providing a way of complementing the previous results. The overall environmental impact has been evaluated by using a normalized graphical representation that can be easily used to compare control strategies from the environmental impact point of view. The pursued analysis can be used as an alternative point of view at the moment of selecting plant operation alternatives.

7 Acknowledgments

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