Ecoefficiency in Portuguese WWTP

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Abstract

Cleaner Production is a strategy that supports companies on their way towards sustainability by focusing their efforts mainly on the reduction of materials' and energy's use, on processes' improvement, on cycles' closing and on waste flows' valorisation or elimination. This approach was used in Waste Water Treatment Plants (WWTP) by considering their running as an industrial process.

In a flowchart all the inputs and outputs were identified. Energy was quantified and the associated costs were allocated. Special attention was paid to energy use in the treatment processes and therefore the higher electricity consumptions were measured. In each WWTP the efficiency in the removal of the pollution load was related to the energy consumption.

For each WWTP an indicator (Value) relating removal efficiency to cost (or energy consumed) was established and used for benchmarking between the target WWTP.

Possibilities, of reduction of materials and energy consumption in the normal functioning of the WWTP, were identified. Other improvement opportunities were detected in what concerns the inputs related to population training and information, namely those related to water savings, internal housing water reclamation and chemicals use.

Keywords: *Cleaner Production, Sustainable Value, wastewater treatment plant, energy efficiency, eco-efficiency*

1. Introduction

With the rising price of energy and resources and the threat of its exhaustion, energy management began to be considered one of the main worries of industrial management (Petrecca 1992; Rohdin and Thollander 2006). Furthermore different stakeholders showed their interest in analyzing and improving the impact of energy consumption of products and processes (Thiede et al. 2013).

About 50% of world energy consumption is due to industrial use (IEA 2013), with consequences in carbon dioxide emissions and climate change. This process calls for the attention of industrial enterprises on the importance of energy efficiency (Worrell et al. 2009) considered at the same level as conventional fuels in the global energy balance (IEA 2013). Reducing energy consumption in industry is therefore an important strategy to achieve the target of energy policies in Europe, of reducing the energy consumption of 20% by 2020 (Trianni et al. 2013).

Society's understanding of what business is expected to contribute for sustainable development has advanced massively. This is no longer about corporate philanthropy or even narrow iterations of corporate social responsibility; companies are expected to create and share value and responsibility across a complex set of economic, social and environmental issues (Buxton, 2012).

The expected answer from companies must consider sustainable production, a responsible attitude and competitive profit, using processes and systems that are non-polluting, that conserve energy and natural resources in economically viable, safe and healthy ways for employees, communities, and consumers and which are creatively rewarding for all stakeholders for the short and long terms (Glavic and Lukmam, 2007).

As defined by the World Business Council for Sustainable Development (WBCSD) in 1992, "eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth's estimated carrying capacity". Various authors say that eco-efficiency (Schmidheiny, 1992) can help the sustainable development of any kind of business activity (Howgrave-Graham and van Berkel, 2007; van Berkel, 2007).

The concept of sustainability is not difficult in understanding, but its implementation in operational terms has shown not to be an easy one (Briassoulis, 2001).

Eco-efficiency becomes then a management strategy towards sustainability by improving the economic and ecological efficiency of companies, attaining a higher Value with fewer inputs, materials and energy and more outputs (product), but fewer waste i.e. pollution in the form of emissions and residues. It lays on the prevention of materials, water and energy losses at the origin, leading to functioning costs reduction and to the improvement of the products environmental profile. The result is a higher Value for companies as well as the increase of their competitiveness. In the past, companies looked at the environment and sustainability as problems, costs and risk factors, but today they see them also as opportunities – sources of efficiency improvement and growth. For example, if energy is saved, both the production costs and the unwelcome outputs, such as waste and emissions are reduced (Henriques and Catarino, 2014).

Although energy efficiency measures are recognized as an important matter and the possibilities of application are wide-ranging, it is still hard to convince companies' top management about its benefits. This is due mainly to the difficulty in demonstrating the resulting savings (Catarino et al., 2015). Other barriers, which make the implementation of the energy efficiency concept difficult, such as organizational, management, financing, government policy, economic, behavioral, training and knowledge and technical (Sorrell et al. 2000; UNEP 2006) must be identified in order to be overcome.

Companies usually classify energy efficiency projects with lower priorities when compared to other considered as strategic investments by being more promising or important (Sorrell et al. 2000; Trianni and Cagno 2012; Schleich 2009; Rohdin and Thollander 2006). Very often the share of energy costs is rather low and this can be the reason why energy efficiency projects are not considered strategic (Catarino, J. at al., 2015).

But eco-efficiency alone is no longer enough. Although it considers economic and ecological aspects, and therefore leads to production processes with fewer resources and less impact in the environment, the social aspects are out of this methodology and nowadays they cannot be forgotten (Picazo-Tadeo et al., 2012).

The Sustainable Value methodology (SVM) is the result of the work of a research team in LNEG, and integrates Value Analysis with eco-efficiency, energy efficiency and cleaner production concepts. The complementarities between eco-efficiency (doing more with less, namely energy consumption) and value analysis (satisfying needs using fewer resources) are visible. Using the synergies between tools used by Value Management (Value Analysis as an example) and eco-efficiency (Cleaner Production CP – UNEP 1990), the Sustainable Value methodology was developed, and integrates the three aspects of Sustainability (economic, environment and social) in Sustainable Value concept (Alexandre et al., 2007; Henriques et al., 2009; Henriques and Catarino, 2014).

The concept of Value has been used with different meanings and scopes in business world in the last centuries. More recently several authors introduced the concept of Sustainable value and those differences can also be found (Hahn et al., 2007; Kuosmanen and Kuosmanen, 2009).

The SVM approach follows the Value definition in Value Management European Standard EN 1325-1, in which value is the relationship between the satisfaction of needs and the resources used in achieving that satisfaction" (Fig.1) and explicitly takes into account the three dimensions of sustainability.

$$\text{Value } \alpha \frac{Satisfaction\ of\ needs}{Use\ of\ resources}$$

Fig. 1. Value Definition

According to EN 12973 Value is not absolute but relative and may be viewed differently by different parties in differing situations. The symbol α in figure1 means that the relationship between needs and resources is only a representation and that they are traded off one against the other in order to obtain the most beneficial balance. The optimization is achieved by balancing the amount to which needs are satisfied against the resources utilized in doing so. Within an organization, improved value may be represented by changing the way in which processes are carried out so that the same outcome is achieved or improved, using fewer resources for example. Value is therefore an indicator that enables to compare the initial solution with the improvement proposals, resulting from the methodology application, and choose the one with a higher value.

The approach to the project, presented in this paper, starts from the premise that it is possible to reduce energy requirements in WWTP. Investment may be necessary, but if energy reduction can be attained at a reasonable cost, this opportunity will be advantageous. And if energy saving is considered when the objectives of the project are defined, saving perspectives will be greater.

The results of energy audits carried out by SAIC (2006), show that no matter its dimension every Wastewater Treatment Plant presents improvement opportunities concerning energy savings. Those savings can vary from 20 up to 40% and in some specific cases even more (there are examples where 75% were attained). Aeration operations are the ones showing a higher potential for savings. Sometimes small changes either to the equipment or the operations can lead to significant savings. Information and training activities in energy management, at all levels, are necessary and useful.

2. Study in 14 WWTP - Context

AdP – Portuguese Waters is one of the big entrepreneurial groups operating in the environmental sector with the mission of contributing to the solution of national problems in the areas of wastewater sanitation and treatment and recovery of waste, within a framework of economic, financial, technical, social and environmental sustainability. Among the AdP Group operations are the urban and industrial wastewater collection, treatment and disposal, including its recycling and reuse in environment safe conditions.

Sustainable use and preservation of natural resources, equilibrium and improvement of the quality of the environment, equity in access to public services and the promotion of well-being and people's standards of living are fundamental values to AdP Group.

In Portugal, AdP group participates in a set of companies that together with the municipalities provide services to about 80% of the Portuguese population, being responsible for the management and exploitation of infrastructures needed to meet the required levels of public attendance and service quality to comply with the European average and best practices standards. The positive impact of the Group´s activity on environmental quality, public health, customer service levels and global sustainability of the sector is recognized by the sector main regulatory authorities, namely in what concerns the considerable improvement in the quality of water for human consumption as well as the ocean waters.

LNEG collaborated with Schneider Electric Portugal in the development of a project which aim is to improve energy efficiency in 14 WWTP belonging to AdP group.

From 1836 to today, Schneider Electric has transformed itself into the global specialist in energy management. Schneider Electric delivers efficient solutions across the global energy chain, enabling people to experience and transform efficiency together at home, in enterprise, across the grid, in towns and cities, and in energy-poor countries. Integrated and open, their solutions improve financial performance while conserving resources, for a more sustainable world.

3. Methodology

In order to improve energy efficiency in companies of AdP group, some of its Waste Water Treatment Plants (WWTP) were submitted to energy diagnosis, supported by the following tasks:

- Identification of energy sources;
- Energy consumption and costs quantification;
- Consumption evaluation by vectors, processes and equipment;
- Possible correlation between energy consumption and production and / or level of the plant functioning;
- Summary evaluation of the WWTP treatment process, by treatment step and identification of potentialities of process improvements with possible implementation;
- First proposal for possible energy management implementation;
- Technical report with the results of the tasks developed.

In order to accomplish the summary evaluation of the WWTP treatment process and to identify potentialities of process improvements the Sustainable Value Methodology was used (Catarino et al. 2007). Some of the methodology phases were applied in a succinct way and the work done is a good starting point for a future deeper application if the Group Management considers it worth.

During a first visit to each WWTP involved in the project, its treatment processes were identified and its flowchart was established following Cleaner Production procedures. Every general and fundamental step was identified (main unitary operations) as well as the auxiliary ones, those operations that being not part of the process are necessary to make it work (for example maintenance, plant and equipment). In the flowchart all the inputs (materials, energy and water) and outputs (products, emissions and waste) were identified and quantified and the associated costs were allocated. All the inputs and outputs were numbered and differentiated by codes:

- RM- raw material, here the waste water to be treated
- AM - auxiliary material in the process
- E – energy
- W – water
- WS – waste
- AE – emissions
- WW – waste water

The process description by operation, without mentioning technical solutions, leads to a greater level of freedom when looking for improvement alternative solutions. The analysis of the whole process in a flowchart shows the circuits followed by the effluent during the treatment process as well as the internal flows (for instance the identification of utilization of process waters). This enables the identification of potential improvement to what is established in the flowchart.

Generally those WWTP, with a higher treatment level, have higher electric energy needs. On the other hand those plants with biological treatment to remove nutrients have electric energy consumptions 30 to 50% higher in aeration, pumping and solid processing operations when compared with conventional treatments of activated sludge.

Considering that the indicator to be adopted for WWTP should consider the treatment level, and therefore its efficiency, the proposal is to adopt one (value) that takes into account the WWTP environmental performance in what concerns organic load, solid load, nutrients, microbial content and odours removal.

According to EN 12973, a subject Value can be described as the relationship between the satisfaction of need (performance) and the resources used in achieving that satisfaction (Fig. 1).

For each WWTP, and based on this definition, Value was estimated using the relationship between the plant efficiency and the resources used. To estimate Value, different steps of the Sustainable Value Methodology, namely Global Inventory and Functional Analysis, were used. Data collected during the global inventory enabled to estimate the resources used, taking into account energy consumption.

Using Functional Analysis, performance was characterized by the functions that translate the users' needs, and later quantified by the plant efficiency. Functional Analysis is a systematic process that enables to identify, characterise, classify and evaluate the study subject's functions and the relationship between them.

4. Results and discussion

The 14 treatment processes were analyzed and systematized in 14 flowcharts.

Fig.2 shows a general flowchart. The information gathering and analysis enabled the quantification of energy demanding by operation.

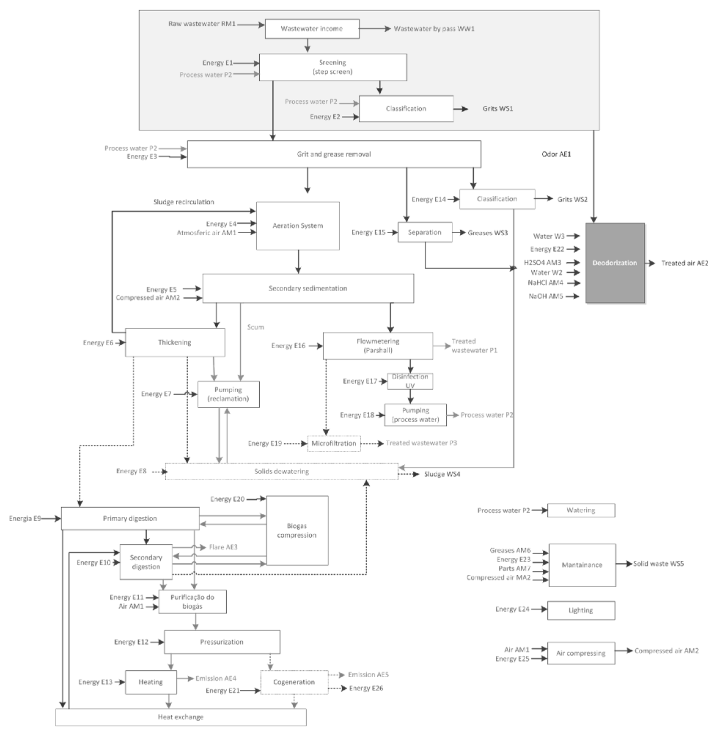

Fig. 2. WWTP general flowchart

Fig.3 shows that a direct relationship between flow rate and total external energy is achieved in the 14 WWTP studied.

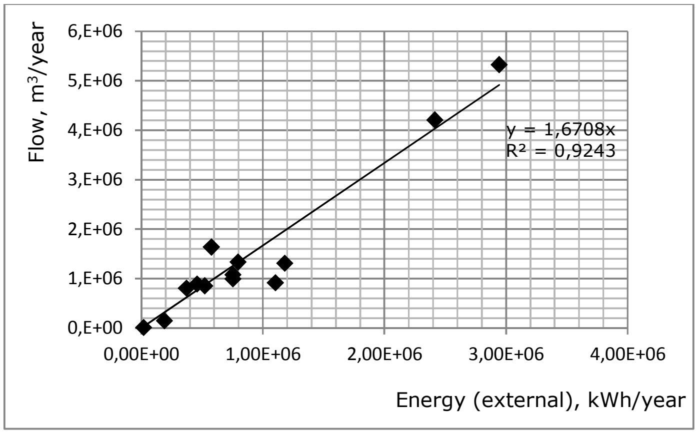

Fig. 3. Relationship between flow rate and total external energy

The information gathering and analysis enabled the quantification of energy demanding by operation. The percentage of energy consumed is shown in fig.4, where the importance, maximum, minimum and medium values for each process operation are registered. The biggest energy consumers are the aeration systems. Air deodorization, flow equalization, and solids dewatering have also a big contribution for the plant energy consumption.

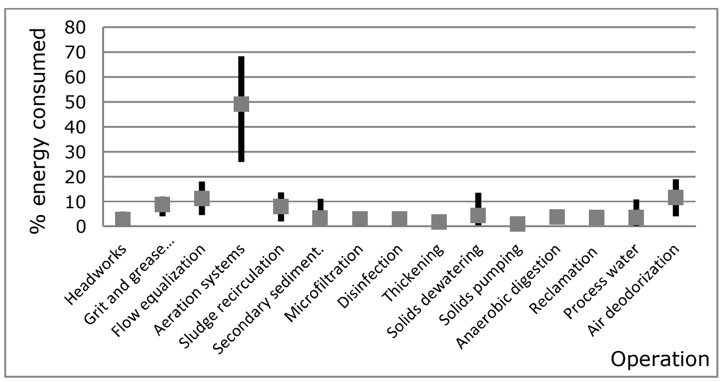

Fig. 4. Consumed Energy in unitary operations

Fig. 4 shows that for this wastewater system sample, 53% of energy demanding is allocated to aeration processes. As to wastewater pumping, it accounts for more than 12% of the overall energy demand. The energy demand of pumping in wastewater systems is largely dependent on the number and size of pump stations in the system and in some cases this operation can be responsible for a large portion of the overall energy demand (i.e. in a flat topography). If the objective is to reduce energy demand, looking at pump stations and energy involved can be a good step.

Functional analysis was developed for the 14 studied WWTP. Fig. 5 shows the example of a WWTP where four functions were identified. A weighting figure (φ) was allocated to each function representing its relative importance in what concerns the stakeholders' expectancies including those concerning existing legislation. In the example presented in figure 5 the following (φ) were considered: remove organic load 40%, remove solids 40%, remove microbial load 10% and remove odors 10%

For each function some criteria were identified and characterized in order to evaluate the function performance. The satisfaction (S) of each function was estimated considering the efficiency in the removal of the elements that justify the existence of that function. Performance is calculated by multiplying the weighting factor φ of each function, which represents its importance relative to the other functions, by the appropriate S factor and summing them. The Value of this WWTP was 111 considering the data analyzed, and was obtained according to the definition by dividing performance (ΣφS) by the resources (R) involved.

For each function some criteria were identified and characterized in order to evaluate the function performance. The satisfaction of each function (S) was estimated considering the flow (m3/year), the initial concentration (g/l) and the removal efficiency (%) concerning several parameters (BOD, COD and solids). For the function "remove microbial load" the satisfaction is zero when the effluent unloaded into environment is submitted to no disinfection, 50% when dechlorination takes place and 100% if UV are used. As to the function "remove odors" three alternatives were considered: no deodorization 0%, odors removal without complete scrubbing 50% or 100% when scrubbing with chemicals.

The Value of this WWTP was 54 considering the data analyzed, and was obtained according to the definition by dividing performance (ΣφS) by the resources (R) involved.

Function	Weighting figures (φ)	Criteria	Satisfaction (S)	Performance φS	Resources (R)	Value Σ φS/R
Remove organic load	40%	Discharge Q Removal efficiency BOD, COD $BOD_{initial}$, $COD_{initial}$	Q x (η_{BODx} x $BOD_{initial}$ + η_{COD} x $COD_{initial}$) = 918834 x (95,9x0,27+88,9x0,88)	$50{,}1\text{x}10^6$	Purchased energy MWh/year 1102,4	**54** (59303715 /1102356)
Remove solids	40%	Discharge Q Removal efficiency TSS $TSS_{initial}$	Q x $TSS_{initial}$ x η_{TSS} 918834x0,21x93,8	$9{,}8\text{ x}10^6$		
Remove microbial load	10%	Discharge Q Type of disinfection	yes Q x 50	$4{,}6\text{x}10^6$		
Remove odours	10%	Discharge Q Type of removal	yes Q x 100	$9{,}2\text{ x}10^6$		

Fig. 5. Functional Analysis – value estimation

As a result of the work developed in those WWTP, following Cleaner Production procedures, some energy efficiency improvement measures, related to good housekeeping, processes changes, equipment modifications, and valorisation can be referred.

Good housekeeping

- Provide covering for grit and grease containers - The waste generated at the entrance operations, grit and grease are sometimes stored at open sky. The waste transport for disposal, which includes energy costs, may be reduced if this waste does not contain rain water, which will happen if the containers are covered.
- Cover the tanks for heat retention - Due to the climate in certain regions, in some periods of the year the effluent surface freezes. In those periods it is convenient to cover the tanks in order to avoid its content freezing. This procedure will reduce energy consumption associated to the treatment when performed at open sky.
- Flows management and discharge measurement - One difficulty found in flows management in WWTP has to do with the inexistence of flow meters. The introduction of flow meters in key points will be a way to support WWTP management in attaining energy efficiency objectives in WWTP.
- Electric equipment adjustment to flow - This measure can be applied in every area of the WWTP. By adjusting motors speed to variable flow the functioning at a constant power is

avoided and therefore energy savings occur. Some studies recommend the adoption of variable-speed drives in electro mechanic equipment. As some secondary effects may occur, before its implementation a deeper study is recommended. Potential advantages of substituting compressors, pumps, blowers or other equipment by two, three, four or five smaller units, which may answer today and tomorrow variable needs, must also be considered. Smaller pumps functioning for larger periods of time is a better solution than having bigger ones designed for higher flows that only occur periodically. The adequate management of flows and waste water treatment, outside the periods when energy is more expensive, will contribute for energy savings

- Pre treatment of waste water from septic pits - Some of the problems of WWTP operation have to do with discharges of waste water from septic pits which occur more frequently in summer and week end periods (WWTP near the beach). A possibility to minimize the effects, which result in a consumption increase in aeration operations and some instability, would be to consider a centralized pre treatment system to reduce the load, namely with anaerobic digestion, before admitting it to the treatment plant.
- Parameters control - The use of sensors to measure inputs and outputs (discharge flow, pressurized air in grit removal, and others) may improve energy efficiency.
- Training/ information about energy reduction potentialities - The training of the technicians involved in the WWTP operation (eventually by e-learning to minimize the interferences with their labor activities), in subjects related with energy management, will be a good input to improve energy efficiency.
- Population involvement - Sensitize the population served by the WWTP for good housekeeping about waste water discharge.
- Dissolved oxygen automatic control / sludge age - Innovative technology to be applied in aeration operations in order to automatically control dissolved oxygen and sludge age to optimize set points and therefore reduce energy consumption maintaining the process performance.
- Integrated control of air flow - Aeration control system that results in a better stabilization and simplification in adjusting the aeration system which becomes more efficient and thus reducing energy consumption.
- Repair dischargers - Whenever the decanter dischargers are not in proper conditions their function will not be correctly performed, so attention must be paid and when necessary repairs must be done.
- Cleaning oxygen probe - Residues that gather on the oxygen probe make difficult its adequate performance, so attention should be paid to its cleanliness.

Process changes

- Aeration with lower energy content - Consider the implementation of lower energy consumers aerators, either by substituting the existing by more modern ones with lower consumptions, or by more efficient ones in what concerns oxygen supply, namely with fine pore diffusers.
- Micro screening need's evaluation - When the water from the decanter has characteristics that enable it to be reused as process water or discharged there is no need for micro screening which represents 5% of energy consumption.
- Alert system for effluent toxicity - The use of effluent's toxicity detectors (bio detectors, metals) will prevent possible disturbance in the microbial population existing in the treatment process.

Equipment modifications

- Sludge dewatering - Dewatering sludge using solar heating will save energy in transportation as well as in the amount of sludge to deposit. It will also improve sludge stabilization improving it for future valorization in agriculture utilization.
- Study aeration system - The substitution of the existing aeration system by another one based on oxygen supplying through bubble diffusers, namely fine bubble ones, will improve the operation and the WWTP capacity of organic treatment. To optimize performance this measure should be combined with dissolved oxygen monitoring and control.
- Double effect aeration system (mechanical mixing) - Beyond the surface agitation if additional energy is supplied at the tank bottom, energy efficiency will improve.

Valorisation

- Make good use of effluents' value - In research: bio plastics production.
- Effluent heat recovery before treatment or discharge to use in the WWTP.
- Kinetic energy recovery resulting from waterfalls.
- Make good use of energy content in effluents to produce electricity

The different Sustainable Value estimated for the 14 WWTP show its relationship with energy used in the process and estimated in a yearly basis (Fig.6) and where other parameters, as referred above, such as the level and efficiency, duly weighted, were considered.

In the three WWTP, which make use of energy content in their effluents to produce electricity, an increase in sustainable value is detected when compared with the necessary consumption if this internal valorization had not occurred (Fig.6)

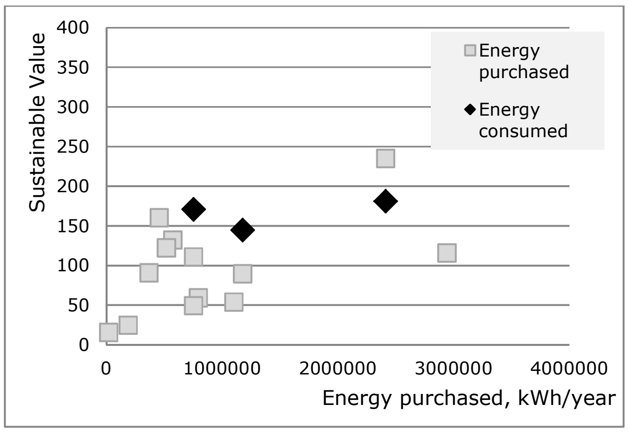

Fig. 6. Relationship between Sustainable Value and energy

For any other proposal implemented the new value must be estimated in order to analyze whether or not improvement occurred. Eventually this methodology can also facilitate a benchmarking study between similar WWTP.

5. Conclusions

Portuguese WWTP present some improvement potential in energy efficiency specially in what concerns good housekeeping. Most of the energy consumed in WWTP, which can attain up to 60% of total consumption, is related to biological treatments. The sample studied showed the existence of a relationship between several parameters namely energy consumption and flow. Sustainable Value seems to be a good performance indicator for WWTP, and presents good potentialities to follow up and monitor the evolution of energy efficiency in processes.

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