Sorting optimal WWTP configurations with resource recovery units under a multi-criteria decision making framework

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Abstract: The effort to upgrade urban WWTP into bio-refineries capable to recover and produce valuable resources is hindered by the fact that technical, economical and environmental impact analysis are complex and time expensive. In the present work, we present a Decision Support System (DSS) that finds an optimal configuration of a WWTP given a set of resource recovery unit processes. For the case study, we consider seven innovative technologies that are tested into the SMART-Plant H2020 project (No.690323). These technologies are modelled and integrated inside a plant-wide model superstructure. We show how the DSS evaluates all the possible plant configurations and how these configurations are sorted by a Multi-Criteria Decision Making (MCDM) method. Plant design optimization is done under dynamic inflow conditions that depend on the local weather history, sewer characteristics and effluent limitations, while sorting accounts for economic, effluent quality and environmental impact multi-criteria.

Keywords: DSS; wastewater; EBPR.

In the last few decades, the wastewater treatment industry has experienced an outstanding rise in the variety of process technologies. Technology selection and benchmarking for plant retrofitting or new design have become more challenging than ever because of the large number of possible plant-designs for a given wastewater treatment problem. On top of this, politic initiatives that promote circular economy motivated the wastewater treatment sector to look for designs that could recover the most of resources from a wastewater stream while still meeting legislation limits. One of the reasons why new technologies for resource recovery are difficult to implement is that a benchmark analysis for a given case study could be very complex. This is a key barrier to their exploitation since it increases the risk aversion of water utilities in moving from conventional technologies to techs with embedded additional benefits from recovery of resources.

DSS tools proposed so far can be classified in two categories: DSS that help the decision maker with a plant design and DSS that improve the management and help to upgrade an existing plant (Guerrero *et al* (2011), Faria *et al* (2016), Solon *et al* (2017) and Torregrossa *et al* (2017)). For plant design, Comas *et al* (2003) and Garrido-Baserba *et al* (2012) proposed a DSS tool that uses a knowledge-based methodology. The main goal of their DSS was to reduce the number of possible plant configurations to a reasonable sub-set of options. Once the sub-set is available, computationally expensive wastewater treatment process design and selection can be performed. Bozkurt *et al* (2015) build a WWTP superstructure made of static process unit models, that use Mixed Integer (Non)linear Programming (MINLP) for optimal plant design. However, superstructure design optimization studies with dynamic ASM/ADM-type models are very rare. Rigopoulos and Linke (2002) build a superstructure based on the ASM1 model that finds an optimal activated sludge process design for a given constant inflow condition, while Guerrero *et al* (2013) benchmarked five types of enhanced biological phosphorus removal (EBPR) configurations with design parameters selected from reference engineering guide-books. However, none of them included inside the study side-stream processes that are known to influence considerably the overall design of the plant.

In order to help water utilities to reduce their risk aversion against new wastewater treatment process units, we propose a DSS that performs an optimal design of hybrid continuous-discrete dynamic plant-wide models. In the following we describe shortly the DSS software architecture which is based on Python and Modelica object-oriented languages. Complex bio-process models are described in MS-Excel sheets, where after a stoichiometric mass balance check, are transformed to Modelica code thanks to a Python' auto-code generation routine. Once the process unit models are available in Modelica, the user should build the predefined superstructure functional stages. A stage represents a section inside a WWTP where the goal of operation is common (e.g. pre-treatment, main-stream activated sludge, effluent refinement, side-stream sludge digestion, etc.). At that point, all the possible configurations for a plant-wide model are automatically assembled. OpenModelica simulation environment compiles and simulates the plant-wide model configurations, while post-processing, optimization and results visualization are done from Python. Post-processing consists in computing the multi-criteria index values and sorting the configurations with Order of Preference by Similarity to Ideal Solution (TOPSIS). Python' optimization algorithms are employed for design optimization and batch-mode stage (process unit model) calibration. The advantage of automatically assembling independent plant configurations is that it allows computations to run in parallel. On the contrary, in a typical MINLP-type superstructure, connectors between process units are enabled or disabled to emulate a certain plant configuration. This means that there is one big model that is simulated where many dummy units waste computational power and is very difficult to run it in parallel. On the other hand, if configurations are build first-hand, the overall code compilation time is higher but single model configuration simulations run faster, they can run in parallel and ad-hoc solver options for each configuration could be set.

Our DSS tries to build on the idea that reliable benchmark analysis of plant designs should be performed within dynamic influent conditions. This is why an influent wastewater model is coupled with the DSS. We take advantage of the E-OBS (Hofstra *et al* (2009)) weather databases of fine-gridded daily mean values, subsequently disaggregated into hourly values, in order to customize the influent wastewater model output in relation to the location of the plant design. It this way, it is possible to study the influence of local weather conditions on the performance of a plant design configuration.

The case study that we present here is the design of a WWTP bio-refinery that can be assembled from seven resource recovery process units tested during the tested during the SMART-Plant H2020 project (No.690323). Those units are a dynamic fine-screen and post-processing of cellulosic sludge (Tech1), a polyurethane-based anaerobic digestion biofilter (Tech2a), a Short-Cut Enhanced Phosphorus and PHA Recovery (SCEPPHAR, Tech2b), a tertiary hybrid ion exchange for N and P nutrients recovery (Tech3), a Short-Cut Enhanced Nutrient Abatement (SCENA) and ordinary digestion (Tech4a), SCENA and CAMBI-enhanced digestion (Tech4b) and a side-stream SCEPPHAR (Tech5). SCEPPHAR and SCENA are sequential batch reactor technologies based on the ASM2d+N2O model proposed by Massara et al (2018). Tech2a and the digester are modelled by ADM1, modified for co-digestion of primary and waste sludge and for phosphorus release/precipitation. Tech3 is a batch process described with a continuous fixed-bed adsorption column model. The only static model is Tech1, where the TSS separation efficiency depends on influent TSS. In Figure 1.1 is represented the superstructure of the plant-wide model made of four stages. Stage1 could have a conventional primary settler (PS) or Tech1, while Stage2 could be empty or have Tech2a instead. Stage3 could be made of a conventional Anaerobic/Anoxic/Oxic system (A2O) or by the resource recovery process units of Tech2b and Tech3. Stage4 models the whole side-stream. Here the reference benchmark plant configuration is Stage1 with PS, Stage2 empty, Stage3 with A2O and Stage4 with a digester unit. Overall, 48 plant configurations are possible and the main goal is to sort them in relation to their economic, effluent quality and environmental impact performances. For Multi-Criteria Decision Making (MCDM), the Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) will be applied.

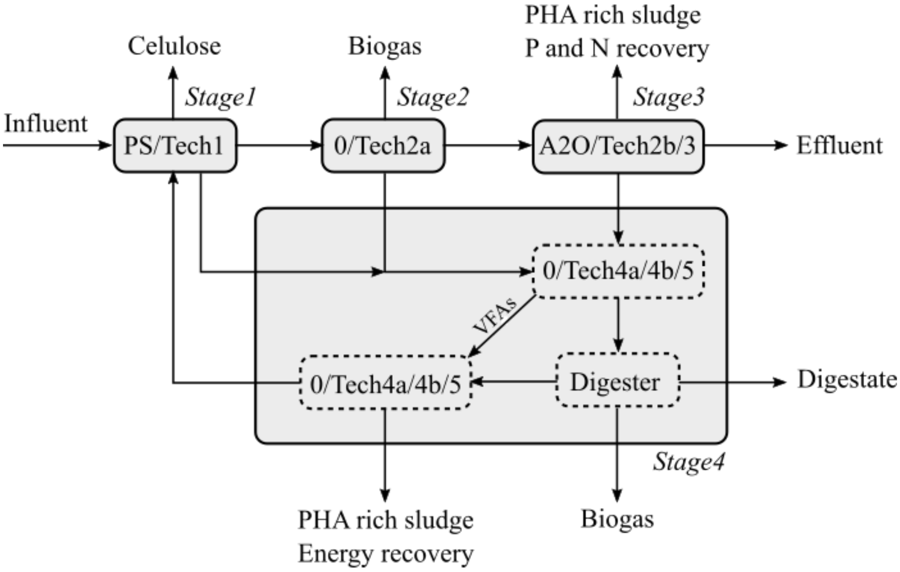

Figure 1.1 WWTP superstructure model diagram.

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