**RETRO-TECHNO-ECONOMIC-ENVIRONMENTAL ANALYSIS (RTEEA) APPLIED TO FIRST- AND SECOND-GENERATION ETHANOL PRODUCTION**

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**Highlights**

* Global sensitivity analysis shows that environmental and economic metrics can be divided in two groups.
* Economic metric (NPV) is influenced mainly by the hydrolysis step.
* Environmental metrics are significantly influenced by the pretreatment stage.

**1. Introduction**

Economic and environmental analysis is an important field in (bio)process engineering, supporting R&D decisions. Process Systems Engineering tools (PSE) allied with techno-economic analysis (TEA) and life-cycle assessment (LCA) can be used to verify process feasibility, to identify possible bottlenecks and optimal operating conditions, among other possibilities. TEA and LCA are usually used to assess the economic and environmental performance of defined process conditions, both structural and operational. RTEA [1] is a novel approach that turns this problem upside down: rather than evaluating the TEA for a predefined processes setup, it provides goals to be pursued by R&D teams, in order to seek feasible operational conditions, based on simulations of the overall process. In this work, RTEA was expanded to RTEEA (Retro-Techno-Economic-Environmental Analysis), incorporating life cycle assessment. RTEEA was applied to the first- and second-generation (1G/2G) ethanol production from sugarcane, using economic and environmental metrics to define feasible regions. Global sensitivity analysis (GSA) was used to identify, with statistical support, critical process variables [2].

**2. Methods**

RTEEA is constituted by four steps: construction of a base case, incorporation of TEA and LCA analysis into the simulation of the process, selection of key variables through global sensitivity analysis and delimitation feasible spaces. The 1G/2G anhydrous ethanol production from sugarcane industrial process was modelled as described by Longati et al (2018). The energy consumption of the plant was optimized through pinch analysis of the process main stream. In this case study, the Net Present Value (NPV) was chosen as the economic metric. The CML-IA baseline V3.04 (World 2000) method was used to perform the life cycle impact assessment (LCIA). The environmental metrics are derived from LCIA. An initial set of variables was chosen using previous knowledge of the process for the global sensitivity analysis through the Sobol method [2]. The main and total Sobol indexes were used to select the process variables. To perform the retro-techno-economic-environmental analysis, it is essential that the variables chosen for analysis are process constraints. If this is not the case, other specified variable, correlated with the desire one, must be freed in order to keep null the degree of freedom of the whole-plant model. The TEA and LCA equations that equal the chosen metrics with a threshold value must be solved together with the model equations of the process (energy and mass balances, thermodynamic relations and so on). In this case study, these equations were NPV = 0 and the CML method environmental indicators of the 1G stand-alone process. The chosen process constraints that satisfy those equations are the output of RTEEA. The platform for the simulations was the software EMSO, which is an equation-oriented simulator.

**3. Results and discussion**

Among more than twenty-seven thousand process variables are present in the biorefinery model. Therefore, an initial ad-hoc selection of variables, based on previous knowledge, had to be made to obtain a treatable set of variables to be spanned by the global sensitivity analysis. The process variables chosen for this case study are related to the steps of bagasse pretreatment, cellulose enzymatic hydrolysis reactor, and xylose fermentation, in the 2G sector of the plant. These steps are still not industrially consolidated, and the information that RTEEA provides may be useful for R&D teams. The GSA pointed out that there are two distinct groups, that encompass various metrics. The first one, composed of the net present value, global warming potential, and photo-oxidation, is mainly influenced by enzyme load and cellulose conversion in the saccharification reactor. The second group, composed of all other metrics, is mainly influenced by the solid mass fraction in the pretreatment stage, and by the cellulose-to-glucose conversion.

**4. Conclusions**

In this work, environmental techno-economic analyses were coupled to derive targets for R&D teams, at early stages of the process development. The RTEEA methodology, an extension of RTEA, was able to identify the process variables that show significant influence on economic and environmental performance of the process, to obtain their threshold values, and to make explicit their relations. A case study was used to demonstrate the methodology capabilities: 1G-2G bioethanol production using sugar cane as feedstock. With this methodology, new goals and directions for process development can be quickly defined.

**References**

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