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Optimal Design and planning supply chains of multi renewable resource-based energy/material applied in process industries

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Abstract

In this work, the effects of multi renewable resource-based energy integration in material supply chains are analysed under stochastic and deterministic conditions. The proposed approach is based on the development of a Multi-objective model to optimize the design and planning decisions of country-size SCs in the existence of conflicting objectives. A multi-scenario mixed-integer linear model is proposed and the capabilities of the approach are examined through a case study from a Sugar cane industry. The integrated energy/material supply chains model shows more economical feasibility than standalone ones and the stochastic solutions in this work demonstrate more robustness in the economic performance of the SC comparing to the deterministic one at any level of the environmental impact. In fact, the stochastic approach optimizes the conflicting objectives as well as improves the whole system robustness compared to the deterministic one and should be therefore the preferred choice in practice.

Keywords: Multi resource-based energy, multi objective optimization, design and planning decision making, stochastic programming, integrated material/energy supply chains

1. Introduction

Renewable resource-based energy generation integrated in material supply chains provides an effective solution for two main problems; energy costs and availability. It reduces the energy costs in process industries while facilitating access to the required energy. Optimization of multi renewable-based energy generation supply chains has recently received much attention. Several models have been proposed as decision support tools for strategic analysis along with planning of bio-energy SCs. For instance, Cambero, et al.(2016), presented a bi-objective bio refinery supply chain optimization model for the production of bioenergy and bio fuels. However, the above authors have not addressed the generic optimization of an integrated material/energy supply chain simultaneously considering both economic and environmental objectives. The proposed approach is based on developing a multi resource-based energy integration MOO model to optimize the design and planning decisions of country-size material/energy SCs in the presence of conflicting objectives.

2. Problem statement

In order to address the objectives previously outlined, the proposed model characterizes a generic multi resource-based energy integration supply chain, as illustrated in Fig. 1, to be used in order to identify and assess new configurations, supporting decisions associated to structural and operational system management.

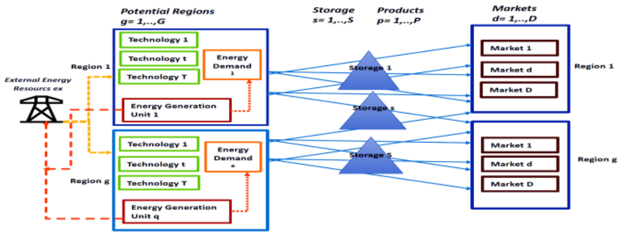

Fig. 1. Renewable based network integrated into a conventional material supply chain

3. Multi-Objective Model

In this work, a scenario-based stochastic MILP formulation is proposed for a given distribution probability for the considered uncertain variables along the considered time horizon. The system is constructed based on two basic models introduced by Mele et al., (2011) (production process part) and Alabert et al., (2016) (multi resource energy generation part). Sizing is constrained to enforce feasibility for all scenarios, and operation variables are calculated according to each scenario. The number of necessary scenarios is set in accordance with the characteristics of the case study to deal with. The model equations are classified as i) production process mass balances and capacity constraints; ii) energy generation energy balances and capacity constraints; iii) integration equations and constraints iv) and v) objective function. The result of the model provides a set of Pareto solutions to be used by the decision maker in order to take the optimum decision. The need to meet the (uncertain) energy demand during a certain period is represented by equation 1:

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$$\sum_{ei} EnIJ_{ei,g,t,sc} \times EfIJ_{ei} + \sum_{ex} EnXJ_{ex,g,t,sc} \times EfIJ_{ex} = TotalDemand_{g,t,sc} \qquad \forall g,t,sc \qquad (1)$$

Where the contributions from sources ei and regions g at time period t for scenario sc $(EnIJ)$ are complemented by the ones from external source x $(EnXJ)$

For the management of the own energy sources, the energy balance in equation (2) considers that all the generated or purchased (*EnXP*) energy has to be consumed or sold (*EnXS*).

$$EfIJ_{ei} \times EnIJ_{ei,g,t,sc} + \sum_{ex} EfIX_{ei} \times EnIX_{ei,g,t,sc} = EnIG_{ei,g,t,sc} \qquad \forall g,t,sc \qquad (2)$$

Energy to be sold can only come from stand-alone generation, and it is considered that extra energy can be accumulated in storage elements.

$$EnXP_{ex,t,sc} = \sum_{g} EnXJ_{ex,g,t,sc} \quad , EnXS_{ex,t,sc} = \sum_{ei}\sum_{g} EnIX_{ei,g,ex,t,sc} \qquad \forall ex,t,sc \qquad (3\&4)$$

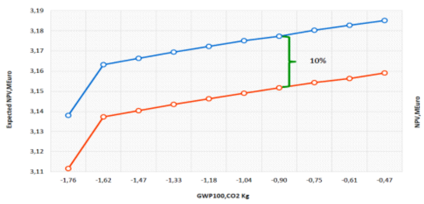
The whole SC system must accomplish two targets: an economic objective, represented by the NPV, and an environmental objective quantified by the global warming potential (GWP). Different NPV values are obtained for each scenario under study, so an expected value E(NPV) of the resulting NPV distribution can be computed by considering the estimated probability for each scenario. The resulting objective functions are finally expressed as follows:

$$Min\{-E[NPV]; E[GWP]\} \qquad \text{S.t. constraints 1-9 and the constraints proposed by Alabert et al., 2016; Mele et al., 2011} \qquad (5)$$

The solution of this problem consists of a set of Pareto optimal SC configurations, which can be identified by applying the ε-constraint method.

4. Case Study and Results

A base case introduced by Mele et al. (2011), which addresses the optimal retrofit of an existing sugar cane industry established in 24 regions of Argentina has been use to illustrate the proposed procedure. Following Illukpitiya et al. (2013) assumptions, the estimated total electricity requirements for internal use in the processing plants is 0.0441 kWh per kg of cane. Figure 2 shows the Pareto curve obtained using the stochastic and deterministic approaches under different CO2 emission levels. Although the economic criteria drops 10% from the deterministic case to the stochastic one, the results are more reliable, flexible and robust in this second one. On the other hand, in the stochastic case, there are more regions involving in energy generation (Fig. 3).



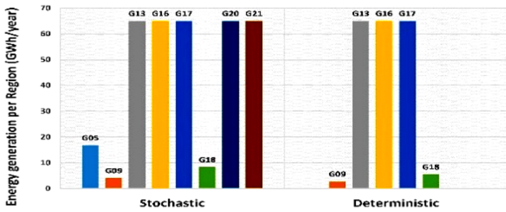


Fig. 2 Pareto set of solutions GWP100 vs NPV

Fig. 3 Energy generation in Deterministic & Stochastic solutions

5. Conclusions

A MILP formulation to address the retrofitting problem of a multi-resource based energy integrated SC under uncertainty has been presented. The model produces a set of feasible energy/material networks addressing the trade-off between conflicting objectives. The capabilities of the model are examined through its application to a case study. The proposed stochastic approach maximizes the expected profit while satisfying a minimum environmental impact for each scenario. The interaction between the objectives has been shown. This way of generating feasible configurations will help the decision-maker to determine the best design according to the selected objectives. In this particular case, the results show that 50% of internal energy demand satisfaction and 94% of biofuel demand can be met by an entirely renewables-based process network, which mainly generates energy through cogeneration units, solar panels and wind power mills.

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