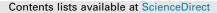
ARTICLE IN PRESS

Energy Conversion and Management xxx (2017) xxx-xxx





Energy Conversion and Management



journal homepage: www.elsevier.com/locate/enconman

Systematic approach for the design of sustainable supply chains under quality uncertainty

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ARTICLE INFO

Article history: Available online xxxx

Keywords: Uncertainty State Task Network Sample Average Approximation Sustainability Quality Industrial symbiosis

ABSTRACT

Sustainable processes have recently awaked an increasing interest in the process systems engineering literature. In industry, this kind of problems inevitably required a multi-objective analysis to evaluate the environmental impact in addition to the economic performance. Bio-based processes have the potential to enhance the sustainability level of the energy sector. Nevertheless, such processes very often show variable conditions and present an uncertain behavior. The approaches presented for solving multiobjective problems under uncertainty have neglected the potential effects of different quality streams on the overall system. Here, it is presented an alternative approach, based on a State Task Network formulation, capable of optimizing under uncertain conditions, considering multiple selection criteria and accounting for the material quality effect. The resulting set of Pareto solutions are then assessed using the Elimination and Choice Expressing Reality-IV method, which identify the ones showing better overall performance considering the uncertain parameters space.

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1. Introduction

During the last decade, industrial globalization has been continuously changing the business behavior, thus making it difficult to remain competitive in the global market for current processes/industries [1]. Additionally, the increasing government pressure on designing green processes has led to the need for developing more sophisticated strategies to design and manage industrial processes. The above together with the recent improvements in environmental analysis techniques has stimulated the emergence of sustainability strategies in process systems engineering (PSE) literature [2]. Here, one major challenge concerns how to combine multi-objective (MO) [3] approaches (maximize economic performance while minimizing environmental impacts) with uncertainty strategies for a reliable/quick response to unpredictable situations (including demands, prices, availability and quality uncertainties) [4].

Along these lines, industrial symbiosis (IS) appears as a promising strategy to bring together companies from different sectors in order to share resources (such as energy, materials and water) and provide stability to the markets [5]. The concept of IS covers multiple important gaps in the current PSE literature [6], since it

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http://dx.doi.org/10.1016/j.enconman.2017.02.060 0196-8904/© 2017 Elsevier Ltd. All rights reserved. attempts to enhance the process sustainability as well as the financial and social benefits for all the participants [7]. Nevertheless, in practice the application of IS strategies is a hard task to carry out, mainly due to the limited flow of information within industries, the lack of integration strategies, the complexity of synergy identification and the dynamic behavior associated to IS networks. In fact, several authors agree that in order to meet the highest sustainability standards, the synthesis and operation of robust industrial symbiosis systems should be improved in parallel with solution strategies for highly complex design and planning optimization problems [8]. Therefore, robust and flexible mathematical formulation should be developed to address IS problems using a PSE approach.

In the PSE literature, bio-based processes can be mentioned as one of the most representative example of IS, especially because of their structural and conceptual similarities. Actually, in the field of bio-based processes, multiple works can be found focusing on operating conditions, equipment units' efficiency, and raw material properties, among others. For example, Mikulandrić et al. [9] use an Artificial Neural Networks (ANN) method to predict the variability of the operational conditions (i.e., output temperatures) and model the dynamic behavior of a biomass gasification unit for its use in on-line applications. The above study uses a surrogate model which requires experimental training data. In parallel, Sepe et al. [10] combine traditional gasification techniques with a

Please cite this article in press as: Medina-González S et al. Systematic approach for the design of sustainable supply chains under quality uncertainty. Energy Convers Manage (2017), http://dx.doi.org/10.1016/j.enconman.2017.02.060

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Nomenclature

| Abbreviations Density | | | | |
|---|------------------------|--|---------------------------|---|
| SC Supply chain FCT _{JR} Fixed cost per unit of technology j capacity at location f MUM Mixed integer linear programming Increment of capacity equal to the upper limit in inter- wal k for technology in facility f STN State task network Interset TM Discount rate LCL Life cycle assessment M Big positive number LCL Life cycle inversory Norm ^F Normalizing factor of damage category g LCH Low voltage Price of products at narket f in period t LW Low voltage Price of products at narket f in period t LW Low voltage Price of products at narket f in period t LW Value of information Z _{inf} MAR Antificial neuronal network Z _{inf} MAR Antificial neuronal network Z _{inf} Indexes Big positive number Sample site f Origin sites Big f Destination sites Fig f Drigin sites Big f Drigin sites Big <td></td> <td></td> <td></td> <td></td> | | | | |
| MOD Mulf-objective optimization in period i MUP Mixed integer lines programming iff Process systems engineering iff SAM Ample average approximation iff STM State task network in period i LCL Life cycle assessment in period i LCL Life cycle assessment in period i LCL Life cycle inventory hormalizing factor of damage category g LCL Life cycle inventory hormalizing factor of damage category g LCV Low voltage hormalizing factor of damage category g LCV Low voltage hormalizing factor of damage category g MW Medium voltage hormalizing factor of damage category g MW Low voltage hormalizing factor of damage category g MW Low voltage hormalizing factor of damage category g MW Medium voltage hormalizing factor of damage category g MW Medium voltage hormalizing factor of damage category g MW Medium voltage hormalizing factor of task for consumption of materials in equipment j Murdie factorial state for damage | | 5 | | |
| MILP Mixed integer linear programming Figure Increment of capacity equal to the upper limit in inter- val for technology in facility f SKM State task network IntersetWith Normalizing factor of damage category g ILC Life cycle assessment M Mormalizing factor of damage category g ILC Life cycle assessment M Mormalizing factor of damage category g ILV Low voltage Mormalizing factor of damage category g ILV Low voltage Price of product s at marker of capacity equal to the upper limit of interval k for technology in facility f ILV Low voltage Price of product s Price of product s at infor production of material s in equipment j MMP Moisture constant Mostisure constant Mostisure for task i for production of material s in equipment j MRP Material state J Technology (treatment/pre-treatment equipment's) Mass faction of task i for consumption of material s in equipment j J Task J Origin sites Pure famility in intervice of task i performed in equipment j J Task Task in the owneent as a sectaria of the product on a material s in equipment j J Technology (treatment/pre-treatment equipment's) Task in theronogy in task in thero | | | FCFJ _{jft} | |
| PSE Process systems engineering val k for technology in facility f SM Sample average approximation rate STM State task network Indicity f State task network Indicity f Indicity f STM Marchial state Indicity f MW Medium woltage Investment required for an increment of capacity equal to the upper limit of interval for materials in equipment f MW Artificial neuronal network Task net onal native network ST Tochnology (treatment/pre-treatment equipment's) Indices State task network State in task network Interval for piecewise approximation (economics) State in task network Interval for piecewise approximation (economics) State in task network Interval for piecewise approximation (economics) State in task network Interval for piecewise approximation (economics) State in task netw | | | EElimit | |
| SAMSample average approximationrateSTNState task networkInvest.MinLGLLife cycle assessmentMLGLLife cycle networkMormalizing factor of damage category gFIndustrial symbiosisPrice of product s at marker in period tC-GCGasfier Internal Combustion EnginePrice of product s at marker in a marker in a second to the upper limit of interval k for technology j in facilityLWLow voltagePrice of product s at marker is and scenario cWMMedium voltagePrice of product s at a steraria s and scenario cUMLow voltagePrice of product s at k if or production of material s in equipment jLHVLow erhating valuePrice of product s at k if or production of material s in equipment jMNArtificial neuronal networkPricesMaterial statePricejTechnology (traument/pre-treatment equipment's)PricejTechnology (traument/pre-treatment equipment's)Price< | | | гс _{jfk} | |
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| Industrial symbiosis Pricea Pric | | | | |
| G-CE Gasifer Internal Combustion Engine Price gim IV Low voltage Price gim MV Medium voltage Price gim MV Medium voltage Price gim MV Medium voltage Price gim MV Moisture content Woiture MC Moisture content Woiture MP Micronized food products Price gim ANN Artificial neuronal network Price gim s Material state Price gim j Technology (treatment/pre-treatment equipment/s) Fig. g Endpoint damage charcetrization factor for environmental intervention a g Endpoint damage category Fig. | | | | |
| LV Low voltage The upper limit of interval k for technology j in fach if f WV Medium voltage if f LHV Lower heating value Tortuosity MC Moisture content Water new Wit value of information day MP Micronized food products day MW Artificial neuronal network day MW Artificial neuronal network day Mainter for the interval k for consumption of material s in geupment j material s in factor for environ- Indices fg Material state fg S Technology (treatment/pre-treatment equipment's) day mental interval for production of cation j f Origin is ites fg' Unitary cost associated with hask i performed in equipment's) f Task fg' Unitary cost associated with handling the inventory of material s in location f and payable to external supplier f Dreipier site fg' Unitary cost associated with handling the inventory of material s and secanarios f Task hat produce material s fg'' Unitary cost associated with handling the inventory of material s and secanario c f Task that consume material | | | | |
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| LHVLower heating valueTormostly factorMCMoisture contentWater_aOPMOperation and maintenanceWater_aMIValue of informationWater_aMPMicronized food productsMaximu moisture for task i for production of material s inMNArtificial neuronal networkTakindicesTaskfor consumption of material s inequipment jTaskfor consumption of material s inindicesfullFachology (treatment/pre-treatment equipment's)fachology j capacity thatindicesfullOrigin sitesfullfOrigin sitesfullfachology j by task i whosefOrigin sitesfull revention afull revention afTaskfull revention afull revention afTime periodfull revention afull revention agEndpoint damage categoryrevental supplieregEndpoint damage categoryrevental supplierfull revention fand payable to external supplierfTask that produce material sfull revention fand payable to external supplierfTask that provide raw material sfull revention fand payable to external supplierfTask that provide raw material sfull revention fand payable to external supplierfTask that provide raw material sfull revention fand payable to external supplierfTask that provide raw material sfull revention fand payable to external supplierfTask that provide raw material sfull | | | | |
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Please cite this article in press as: Medina-González S et al. Systematic approach for the design of sustainable supply chains under quality uncertainty. Energy Convers Manage (2017), http://dx.doi.org/10.1016/j.enconman.2017.02.060

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