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ENVIRONMENTALLY CONSCIOUS SUPPLY CHAIN DESIGN AND CAPACITY PLANNING: FROM FIRST TO SECOND GENERATION BIOFUEL SYSTEMS

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In the search for a viable solution to the current energy supply question and global warming issues, world Countries have been promoting renewable sources as a key aspect of the energy agenda. In particular, great part of policy framework, aiming to relieve oil dependency, is centered on steering biofuels development and penetration in the market. Bioethanol in particular has been assuming a leading position among biofuels and therefore, it might play a major role in establishing a more sustainable energy systems. If on the one side, corn-based technologies (first generation ethanol), representing the most well-entrenched production processes, are now incurring increasing discredits related to their effective sustainability, on the other side, lignocellulosic ethanol (second generation) might be capable of overcoming such drawbacks, but still remains a rather expensive business.

In this context, supply chain optimization may provide decision-making tools to help managing the oncoming transition from first to second generation bioethanol productions. In this work, a multi-objective Mixed Integer Linear Programming is developed to design bioethanol networks where both corn grain and stover are considered as suitable biomass. Environmental and financial performance are simultaneously taken as design drivers and alternative processing technologies options are considered, too. A real world case study is proposed addressing the emerging bioethanol production in Northern Italy. Results show how the design transition from first to second generation bioethanol systems substantially depends on the specific trade-off between environmental and financial objectives.

1. INTRODUCTION

During recent years, renewable energy has been encountering a growing interest as a means to address the increasing global energy demand reducing the dependency on fossil fuels and mitigating global warming potentials. Biomass has been acknowledged a particular attention due to its suitability not only in providing electric, mechanical and thermal energy, but also as primary source to produce liquid biofuels for automotive purposes. Towards reaching the goal of establishing a more sustainable transport system, the European Union (EU) has been instrumental in promoting biomass-based fuels and binding minimum national targets for biofuels share have been set (EC, 2009); e.g. 5.75% of energy in the transport sector from renewable sources by 2010, up to 10% by 2020. Sustainability criteria have been also established including soil, water, air and biodiversity protection as well as minimum greenhouse gas (GHG) emissions savings from biofuels production and usage with respect to the conventional gasoline-based pathway for eligibility for public incentives (i.e. GHG reduction must reach a minimum threshold of 35% from 2009, 50% from 2017 and 60% from 2018 onwards).

Biomass-based ethanol production more than doubled during the last four years, reaching over 85.6 billion liters in 2010 (Carriquiry et al., 2011), thus assuming a leading position among biofuels in substituting petroleum-based gasoline. Even if its actual carbon footprint is still debated (Fargione et al., 2008), it is generally acknowledged that ethanol fuel can achieve a reduction in net greenhouse gas with respect to oil (Mussatto et al., 2010). Moreover, the manufacture of this fuel at a large scale would have the advantage of improving rural

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economies, as well as increasing and diversifying the employments in the farming lands (Petrou and Pappis, 2009).

Bioethanol current production is based on the so-called first generation conversion technologies, using the products of conventional food crops as feedstocks, as starchy-, sugar- and oil-based resources; e.g. corn, wheat and sugarcane. The wide and enthusiastic support that biofuels were given at the earlier beginning, has eroded more recently as new studies have highlighted their direct competition with food crops (Carriquiry et al., 2011). Furthermore, environmental degradation concerns (e.g. potential contribution to monoculture and deforestation), doubts on actual ability as energy vector to displace fossil fuels (Fargione et al., 2008) as well as the business economic sustainability dependence on feedstocks supply costs (Petrou and Pappis, 2009), have been also affecting first generation ethanol industry growth and social perception (Londo et al., 2010). In this context, the promotion of biofuels produced from cellulosic biomass (second generation biofuels), which does not have any food value, has been strongly recommended. However high capital expenditures and production costs hinder the establishment of second generation facilities at a commercial scale and only pilot or demonstrative plants have been brought into operation (Piccolo and Bezzo, 2009). First lignocellulosic crop residues, being the cheapest and most readily available feedstocks, may greatly extend the potential of ethanol industry (Mabee et al., 2011), thus paving the way to the processing of dedicated energy crops. In particular, corn crop residues (corn stover) with a relatively high abundance and a composition rich in cellulose and hemicellulose are one of the most favorable feedstocks (Petrolia, 2008). Besides, their availability in the same areas as corn grain might ease the revamping of already existing corn conversion plants to a hybrid corn- and stover-based technology. This could represent a great benefit in the way that capital equipment, operating expenses and co-products could be shared to achieve overall savings in comparison with an ex novo second generation plant (USDA, 2005).

In tackling such high-level and multi-faceted decision problems, analytical modeling has been recognized as the best optimization option especially in the early stage of unknown structures design (Beamon, 1998). The full management of production systems is a critical aspect of modern enterprises development (Papageorgiou, 2009) and needs adopting a comprehensive approach considering all the stages belonging to the entire production and distribution supply chain (SC). In particular, as stated by Kallrath (2000), Mixed Integer Linear Programming (MILP) represents one of the most suitable tools in determining the optimal solutions of complex SC design problems where multiple alternatives are to be taken into account.

A relatively large number of recent works have proposed a comprehensive optimization approach in the design of bioenergy supply chains (Bruglieri and Liberti, 2008; Rentizelas et al., 2009). Other studies have focused on the adoption of techno-economic drivers in facing the design of the whole biofuel system. Dunnett et al. (2008) first proposed a steady-state spatially explicit MILP model to determine the cost optimal configuration for a lignocellulosic bioethanol SC. Zamboni et al. (2009a) presented a spatially-explicit MILP model for the integrated management of the key issues affecting corn-based ethanol SCs such as biomass suppliers and production facilities allocation as well as transport logistics. More recently, Zhu et al. (2011) provided a decision-making tool to support strategic supply chain design and tactical scheduling for converting switchgrass to biofuel. Papapostolou et al. (2011) presented an MILP mathematical model for the optimization of biodiesel network using SC income maximization as a driver. Finally, Marvin et al. (2011) developed an MILP modeling framework for the economic optimization of an ethanol fuel SC using lignocellulosic residues as feedstocks for ethanol production and accounting for biomass spatial availability.

However, decision makers should be provided with tools for analyzing the overall supply chain, not only assessing the economic, but also the environmental pros and cons so as to define the most convenient strategies concerning the development of the future road transport systems. In fact, biofuels SC analysis (SCA) should integrate economic aspects along with the environmental responsibility of the production network, such a design process considers environmental concern as a new design objective and not merely as constraints in operations, according to the concept of Green Supply Chain Management (GrSCM) (Hugo and Pistikopoulos, 2005). GrSCM peculiarity is to effectively embody the Life Cycle Analysis (LCA) approach within the SC Analysis (SCA) techniques aiming at a quantitative assessment of the environmental burdens of each SC stage. In this context, mathematical programming techniques offer a general framework for including environmental concerns in the design of chemical processes through a Multi-Objective Mathematical Programming (MoMP), which improves decision-making progress particularly at the early stage of process development enabling simultaneous consideration of conflictive criteria (Grossmann and Guillén-Gosalbéz, 2010).

Recent works have been addressing GrSCM through a MoMP approach. Hugo and Pistikopoulos (2005) proposed a modeling framework combining plant location and capacity planning features with the principles of LCA for the strategic design of fuels SCs. Bojarski et al. (2009) addressed a multi-objective MILP (MoMILP) optimization tool dealing a design planning problem observing tradeoffs between environmental damage categories and economic indicators. Zamboni et al. (2009b) developed a static spatially explicit MoMILP framework which minimizes both the operating costs and the GHG emissions of a corn-based ethanol SC. Mele et al. (2011) proposed a bi-criteria model addressing both profit and environmental impacts of combined sugar/ethanol SCs by adopting the eco-indicator 99 and global warming potentials.

Here an MoMILP approach is proposed and implemented to design first and second generation corn- and stover-based bioethanol SCs considering their mutual integration, encompassing alternative production technologies as well as optimizing the biofuel system according to both economic and environmental criteria. The work is devoted to delivering an environmentally conscious decision-making tool based on a multi-period MoMILP modeling framework for the optimization of corn grain- and stover-based bioethanol production systems. Technological alternatives are characterized by varying biomass mix between corn grain and stover for bioethanol production. In addition, valuable by-products (i.e. DDGS, Distiller's Dried Grains with Solubles) and stover use to produce energy are investigated as suitable alternatives to improve the environmental performance of the system.

The economics of the system is assessed by means of SCA techniques, focusing on biomass cultivation size, technology selection and plant capacity. The environmental performance of the system is evaluated in terms of GHG emissions, by adopting a Well-to-Tank (WTT) approach to LCA analysis (CONCAWE, 2007).

2. ASSUMPTIONS AND METHODS

The core task of this work is the development of a design tool to steer decisions on general biofuel SC over the long term. This is performed through an optimization problem driven by both profit maximization and impact minimization criteria. The objective is to determine the optimal system configuration which maximizes the financial profitability while minimizing the GHG emissions. Therefore, key variables to be optimized deal with the best bioethanol SC design in terms of

i. feedstock mix
ii. plant capacity and conversion technology
iii. by-products end-use options
iv. financial performance of the system over the long term
v. system impact on global warming.

The problem refers to a single bioethanol production plant which is supplied with the necessary biomass (corn, stover or both) cultivating a hypothetical land surface of limited, although flexible, extension. The financial analysis is assessed through a multi-period modeling pattern for the NPV index implementation, supporting an environmentally conscious investment planning over a 20-years time horizon.

Referring to fuel production, ten technologies were taken into account (Table 1): first generation from corn (dry-grind process, DGP) (Zamboni et al., 2009b), second generation from stover (lignocellulosic process, LCEP) (USDA, 2005), and integrated technologies (Hybrid, characterized through purpose-designed Aspen models), where the feedstock mix describes three decreasing corn to stover ratios (1:1,1:2,1:3). Finally, the use of by-products (i.e. DDGS, Distiller's Dried Grains with Solubles) and stover as alternative fuels to natural gas (NG) for the combined heat and power station (CHP) were investigated.

Table 1. Conversion technologies assessed in the study for ethanol production.

Process	Biomass-to-		Fuel to CHP			Output		
	Corn	Stover	NG	DDGS	Stover	Ethanol	CHP	DDGS
DGP	•		•			•		•
DGP-CHP	•			•		•	•	
DGP-	•				•	•	•	•
LCEP		•				•	•	
Hybrid†	•	•			•	•	•	•
Hybrid-	•	•		•	•	•	•	

†Each Hybrid technology comprises three instances at varying biomass mix.

The whole SC analysis has been limited to the upstream biofuel production involving biomass cultivation and delivery as well as fuel production sites. Impact assessment over the entire biofuel life cycle refers to the standard Lifecycle Assessment (ISO, 1997) and has been limited to the WTT (Well-to-Tank) approach (Zamboni et al., 2009b).

The approaches proposed by Zamboni et al. (2009b), have been adopted to evaluate the modeling parameters related to the corn-based SC and LCA issues. Such hypotheses were extended to the stover pathway. However, biomass harvest, collection, drying and transformation stages were modeled as in the reposts by ANL (2006) and USDA (2005).

3. MATHEMATICAL FEATURES

The problem is formulated as an moMILP model based on the mathematical approaches commonly adopted in the strategic design of multi-echelon SCs (Tsiakis et al., 2001). It also embodies different features to address the capacity planning and technology selection (Liu et al., 2007) of fuel systems design at the strategic level. The environmental frame as well as the moMILP solution algorithm are approached as in (Hugo and Pistikopoulos, 2005).

The first objective considered here is the NPV (Obj_{NPV} [€]) of the business to be established. This imposes the maximization of profit-related indexes, and hence the Obj_{NPV} value is required to be written in its negative form. It is calculated by summing up the discounted annual cash flows minus the capital investment when a production facility is established. The economic objective function is stated as follows:

$$Obj_{NPV} = -NPV = -\sum_k \left(\left(\sum_t CF_{k,t} \cdot df_t \right) - TCI_k \right) \quad (1)$$

where $CF_{k,t}$ [€/y] represents the annual cash flow; TCI_k [€] stands for the capital investment related to the establishment of a production facility of technology k; and df_t is the discount factor related to each year t.

The second objective is to minimize the total GHG impact (Obj_{ENV} [kg of CO_2-eq]) resulting from the operation of the biofuel SC over the 20 years horizon. This is estimated by summing up the annual impact $TI_{k,t}$ [kg of CO_2-eq/y] resulting from the operation of the production chain for each year t and when a conversion technology of type k is chosen. The definition of $TI_{k,t}$ needs considering each life cycle stage s contribution to the overall GHG impact as well as the effect of emission credits coming from by-products allocation. Accordingly:

$$Obj_{ENV} = \sum_{k,t} TI_{k,t} = \sum_{k,t} \left(CRD_{k,t} + \sum_s Imp_{s,k,t} \right) \quad (2)$$

where $Imp_{s,k,t}$ [kg of CO_2-eq/y] is the GHG emission rate resulting from the operation of each single stage *s* at time *t* when a technology *k* is chosen, whereas $CRD_{k,t}$ [kg of CO_2-eq/y] represents the emissions discount for technology *k* at time *t*. The GHG emission rate is defined as follows:

$$Imp_{s,k,t} = \sum_i f_{s,i} \cdot F_{s,i,k,t} \ , \quad \forall\ s,k,t \tag{3}$$

where the reference flow $F_{s,i,k,t}$ [units/y], specific for each life cycle stage *s*, biomass *i* and technology *k* is multiplied by a global emission factor, $f_{s,i}$ [kg of CO_2-eq/unit], representing the carbon dioxide emissions equivalent at stage *s* for treating biomass *i* per unit of reference flow. In particular, $F_{i,k,s,sc,t}$ is represented by the feedstock rate for biomass cultivation, delivery and pre-treatment stages of the LCA, while it is equal to the ethanol rate accounting for fuel production step.

The emissions discount is given by:

$$CRD_{k,t} = -c_k \cdot P_{'ethanol',k,t} \ , \quad \forall\ k,t \tag{4}$$

where c_k [kg of CO_2-eq/t] represents the emission credits assigned to cattle feed and/or energy displacement per unit of ethanol rate, $P_{'ethanol',k,t}$ [t/y], produced through technology *k* at time *t*. This formulation imposes that the primary product has to be charged of the total GHG emissions, minus the emission credits derived from the displacement of alternative goods with by-products. With concerns to the corn-based bioethanol system, DDGS is the main by-product, which could be a valuable substitute for cattle feed and may also be used as a fuel for CHP generation. On the other hand, stover-based processes deliver electricity as main by-product, generated from the valorization of stover lignin in a CHP system.

4. RESULTS AND DISCUSSION

The two objective problem was solved through the CPLEX solver in the GAMS® modeling tool (Rosenthal, 2006). Figure 1 shows the resulting trade-off set of non-inferior solutions and their trend reveals the existing conflict between environmental and economic performance.

The economic optimum (point A in Figure 1) involves the selection of the standard DGP technology in which DDGS is sold as animal fodder. This option allows for more revenues coming from the by-product business and results in a normalized NPV of about 1.61 €/GJethanol. The environmental outcomes show an overall GHG emission of 78.03 kg CO2-eq/ GJethanol which leads to an emissions reduction of about 9% with respect to the conventional gasoline pathway. These results are not surprising and match the usual performance of first generation ethanol productions. In fact, from an economic standpoint corn-based technologies are acknowledged to perform better than lignocellulose-based ones, mainly because of less capital expenditures and production costs involved in the SC operation, particularly when economy of scale is exploited, too (p = 276 kt/y, i.e. maximum plant capacity). On the other hand, the resulting 9% emissions savings are insufficient for eligibility for public incentives (asking for at least 35% of GHG reduction with respect to conventional fuels).

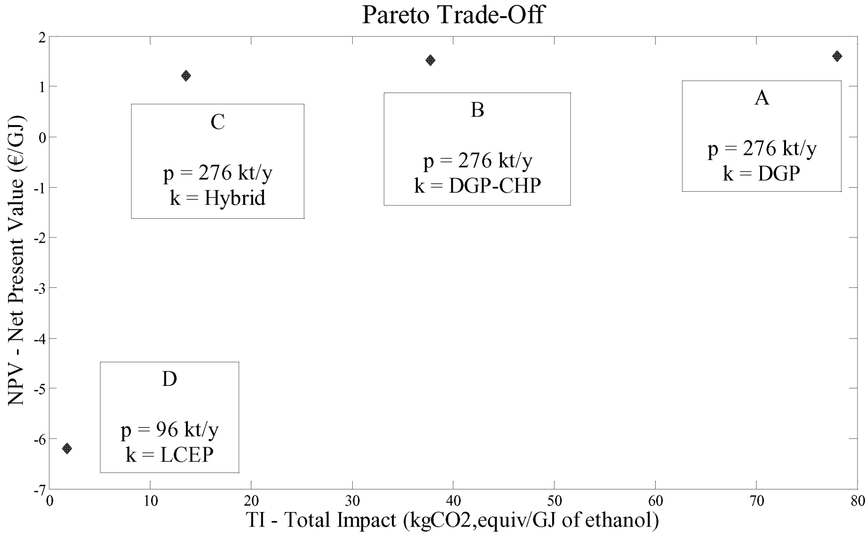

Figure 1. Pareto set of non-inferior solutions: simultaneous optimisation under NPV maximisation and GHG emissions minimisation criteria (p = plant scale; k = production technology).

Moving down towards better performance in terms of environmental impact mitigation and still keeping high financial levels, a suitable technological option is represented by the Pareto non-inferior point B in Figure 1: this would involve the establishment of a production facility still exploiting the technology DGP (k = DGP-CHP) and operating at maximum capacity (p = 276 kt/y). This option takes advantage of burning DDGS in the power station: as shown in Figure 2 in spite of the higher capital expenditures (26 €/GJethanol against the 20 €/GJethanol needed to establish the standard DGP facility), this solution would lead to a global decrease in ethanol production costs due to the heavier effect of energy supply savings which still allows for good revenues (the normalized NPV is now 1.52 €/GJethanol). As shown in the emissions breakdown reported in Figure 3, this process design entails substantially larger emission savings due to higher emission credits coming from the alternative use of by-products. The overall GHG emissions are about 56% lower with respect to gasoline, thus matching the EU requirements for 2017 (i.e. 50% savings).

If the 2018 emission target (i.e. 60% savings) has to be reached, solution C (Figure 1) is suggested: this supply chain configuration may provide very positive effects on global warming mitigation leading to an overall GHG savings of about 84%. This performance is achieved by operating the Hybrid technology at the maximum capacity (p = 276 kt/y): as shown in Figure 3, although higher emissions for biomass distribution and lower credits come from the current by-product end-use, the bioethanol production determines a lower impact when stover is used. On economic terms (Figure 2), the higher investment to the establishment of hybrid technologies (about 51 €/GJethanol) entails a consistent worsening on the economic performance. As a result, the solution indicates a normalized NPV of 1.21 €/GJethanol which is about 20% worse than solution B (25% worse than solution A).

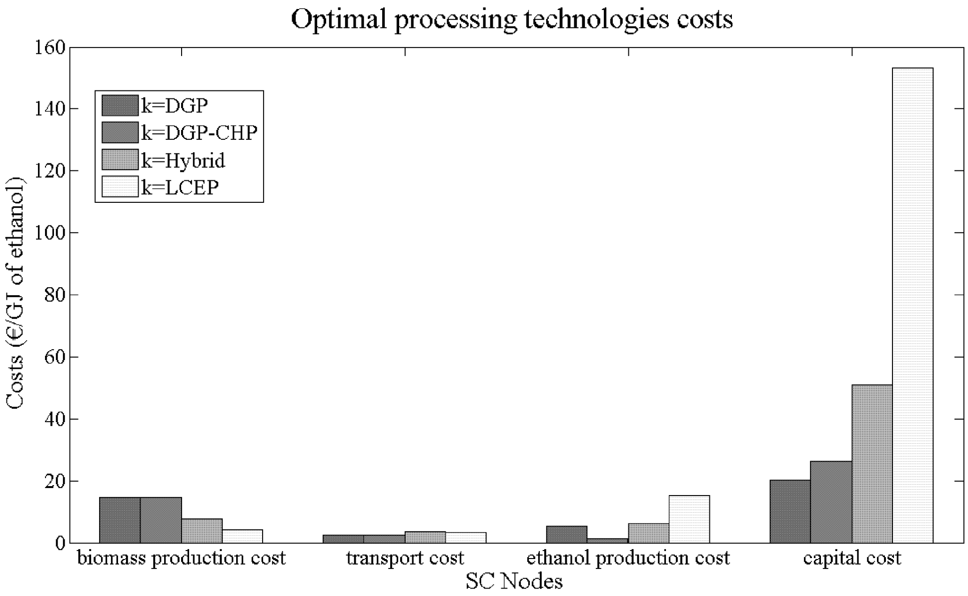

Figure 2. Non-inferior Pareto solutions: costs breakdown(k = production technology).

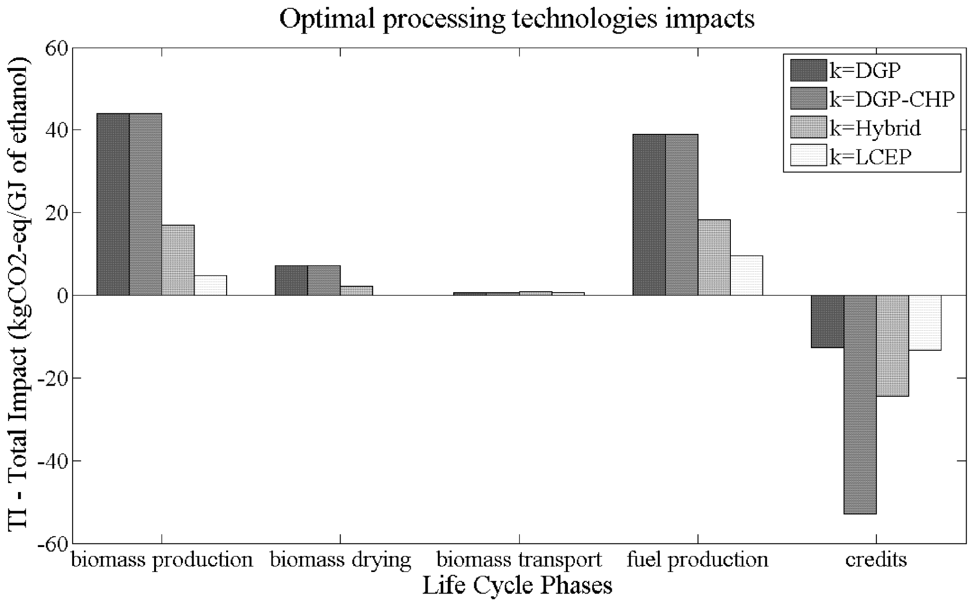

Figure 3. Non-inferior Pareto solutions: emissions breakdown(k = production technology).

Eventually, the environmental optimum is reached with configuration D (Figure 1): it involves the establishment of a full second generation facility (technology *k* = LCEP) operating at minimum capacity (*p* = 96 kt/y) and with an impact on global warming reduced to only 1.8 kg CO_2-eq/$GJ_{ethanol}$ (about 97% less than gasoline). This is mainly due to the lower emissions resulting from stover production and conversion to ethanol when compared to conventional first generation biomass: as shown in Figure 3, stover cultivation results in nine-fold lower emissions than grain cropping, whereas second generation fuel production impact is four times lower than the first generation one. Although the remarkable performance in terms of global warming mitigation, this solution is not economically feasible: the normalized NPV drop down to -6.20 €/$GJ_{ethanol}$, which clearly shows the scarce competitiveness of such a business. As Figure 2 reports, this is mainly due to the much higher capital costs (about 153 €/$GJ_{ethanol}$) needed to establish second generation technologies.

5. FINAL REMARKS

A moMILP modeling framework for the strategic design of biofuel systems has been presented and discussed. The aim of the study was to build a general modeling tool that might be helpful to steer the transition towards more sustainable second generation productions under both economic and environmental criteria. Results show how first generation technologies, although more competitive within the conventional fuel market, are not a sustainable answer to the energy supply question, particularly if the EU legislation is taken into account. Although current stand-alone cellulosic technologies are not viable on economical terms, integrated corn grain and stover technologies may allow for a significant reduction of GHG emissions (abiding by the EU emission limits) and still deliver a profitable business.

6. REFERENCES

ANL, 2006, Fuel-Cycle Assessment of selected Bioethanol Production Pathways in the United States, Argonne National Laboratory: Argonne, Illinois.

Beamon B., 1998, Supply chain design and analysis: Models and methods, International Journal of Production Economics 55, 281–294.

Bojarski A.D., Laìnez J.M., Espuña A., Puigjaner L., 2009, Incorporating environmental impacts and regulations in a holistic supply chains modelling: An LCA approach. Computers and Chemical Engineering 33, 1747-1759.

Bruglieri M., Liberti L., 2008, Optimal running and planning of a biomass-based energy production process, Energy Policy 36, 2430-2438.

Carriquiry M.A., Du X. and Timilsina G.R., 2011, Second generation biofuels: Economics and policies, Energy Policy 39, 4222-4234.

CONCAWE, EUCAR and JRC (CONCAWE), 2007, Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context: WELL-TO-TANK Report. Version 2c, European Commission, Brussels.

Dunnett A., Adjiman C.S. and Shah N., 2008, A spatially explicit whole-system model of the lignocellulosic bioethanol supply chain: An assessment of decentralized processing potential, Biotechnology for Biofuels 1, 13.

European Commission (EC), 2009, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Parliament, Brussels.

Fargione J., Hill J., Tilman D., Polasky S. and Hawthorne P., 2008, Land clearing and the biofuel carbon debt, Science 319, 1235-1238.

Grossmann I.E., Guillén-Gosalbéz G., 2010, Scope for the application of mathematical programming techniques in the synthesis and planning of sustainable processes, Computer and Chemical Engineering 34, 1365-1376.

Hugo A., Pistikopoulos E.N., 2005, Environmentally conscious long-range planning and design of supply chain networks, Jorunal of Cleaner Production 13, 1471–1491.

International Organization for Standardization (ISO), 1997, ISO 14040: Environmental Management-Life Cycle Assessment-Principles and Framework; International Organisation for Standardisation, Geneva.

Kallrath J., 2000, Mixed integer optimization in the chemical process industry: Experience, potential and future perspectives. Chemical Engineering Research and Design 78, 809–822.

Liu P., Gerogiorgis D.I. and Pistikopoulos E.N., 2007, Modeling and optimization of polygeneration energy systems, Catalysis Today 127, 347-359.

Londo M., Lensink S., Wakker A., Fischer G., Prieler S., van Velthuizen H., de Wit M., Faaij A., Junginger M., Berndes G., Hansson J., Egeskog A., Duer H., Lundbaek J., Wisniewski G., Kupczyk A., and Könighofer K., 2010, The REFUEL EU road map for biofuels in transport: Application of the project's tools to some short-term policy issues, Biomass and Bioenergy 34, 244-250.

Mabee W.E., McFarlane P.N. and Saddler J.N., 2011, Biomass availability for lignocellulosic ethanol production, Biomass and Bioenergy, doi:10.1016/j.biombioe.2011.06.026.

Marvin W.A., Schmidt L.D., Benjaafar S., Tiffany D.G. and Daoutidis P., 201, Economic Optimization of a Lignocellolosic Biomass-to-Ethanol Supply Chain, Chemical Engineering Science, doi:10.1016/j.ces.2011.05.055.

Mele F., Kostin A., Guillén-Gosàlbez G. and Jimenez L., 2011, Multiobjective model for more sustainable fuel supply chains. A case study of sugar cane industry in Argentina. Industrial and Engineering Chemistry Research 50, 4939-4958.

Mussatto S.I., Dragone G., Guimarães P.M.R., Silva J.P.A., Carneiro L.M., Roberto I.C., Vincente A. and Texeira J.A., 2010, Technological trends, global market, and challenges of bio-ethanol production, Biotechnology Advances 28, 817-830.

Papapostolou C., Kondili E., Kaldellis J.K., 2011, Development and implementation of an optimization model for biofuels, Energy, doi:10.1016/j.energy.2011.08.013

Papageorgiou L.G., 2009, Supply chain optimization for the process industries: Advances and opportunities. Computers and Chemical Engineering 33, 1931-1938.

Petrou E.C. and Pappis C.P., 2009, Biofuels: A survey on pros and cons, Energy Fuels 23, 1055-1066.

Petrolia D.R., 2008, The economics of harvesting and transporting corn stover for conversion to fuel ethanol: A case study for Minnesota, Biomass and Bioenergy 32, 603-612.

Piccolo C. and Bezzo F., 2009, A techno-economic comparison between two technologies for bioethanol production from lignocellulose. Biomass and Bioenergy 33, 478-491.

Rentizelas A.A., Tatsiopoulos I.P. and Tolis A., 2009, An optimization model for multi-biomass tri-generation energy supply, Biomass and Bioenergy 33, 223-233.

Rosenthal R.E., 2006, GAMS - A Users' Guide (Version 22.5), GAMS Development Corporation, Washington, USA.

Tsiakis P., Shah N., and Pantelides C.C., 2001, Design of multi-echelon supply chain networks under demand uncertainty, Industrial and Engineering Chemistry Research 40, 3585-3604.

USDA, 2005, Feasibility Study for Co-Locating and Integrating Ethanol Production Plants from Corn Starch and Lignocellulosic Feedstocks, USDA, Wyndmoor, Pennsylvania, USA.

Zamboni A., Shah N. and Bezzo F., 2009a, Spatially explicit static model for the strategic design of future bioethanol production systems. 1. Cost minimisation, Energy & Fuels 23, 5121–5133.

Zamboni A., Bezzo F. and Shah N., 2009b, Spatially Explicit Static Model for the Strategic Design of Future Bioethanol Production Systems. 2. Multi-Objective Environmental Optimization, Energy & Fuels 23, 5134-5143.

Zhu X., Li X., Yao, Q. and Chen Y., 2011, Challenges and models in supporting logistics system design for dedicated-biomass-based bioenergy industry. Bioresource Technology102, 1344–1351.