Impact on the optimal design of bioethanol supply chains by a new European Commission proposal

Filippo Mazzetto[a], *Gustavo Simoes-Lucas*[a,b], *Ricardo A. Ortiz-Gutiérrez*[a], *Davide Manca*[c], *Fabrizio Bezzo*[a,*]

[a] *CAPE-Lab – Computer Aided Process Engineering Lab, Department of Industrial Engineering, University of Padova, via Marzolo 9, 35131 Padova, Italy*

[b] *CEG-IST – Centro de Estudos de Gestão, Istituto Superior Tecnico de Lisboa, Avenida Rovisco Pais, 1049-001 Lisboa, Portugal*

[c] *PSE-Lab Process Systems Engineering Laboratory, Dipartimento di Chimica, Materiali e Ingegneria Chimica "Giulio Natta", Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy*

1. Introduction and motivation

Biofuels are acknowledged to have a positive effect in terms of energy security, because they decrease the dependence on fossils of oil-importing countries (Renewable Fuels Association, 2012). Currently most used biofuels based on crops growing in a temperate climate (*i.e.* corn-based ethanol and rapeseed-based biodiesel) may deliver only limited environmental benefits (Farrell et al., 2006) and may lead to severe ethical issues because of the arising competition between food and fuels (Tenenbaum, 2008; Gomiero et al., 2010).

Recently, the European Commission (EC) proposed a revision of the existing Directive (2009/28/EC) that regulates the production of biofuels in the European Union and aims at reaching a quota of 10% biofuels in the transport sector and on energy basis by 2020, in order to promote more sustainable biofuels, both on the environmental and the ethical points of view, while maintaining their role in terms of energy security. In particular, there is a will to "limit the contribution that conventional biofuels make towards attainment of the targets in the Renewable Energy Directive [and to] encourage a greater market penetration of advanced biofuels by allowing such fuels to contribute more to the targets in the Renewable Energy Directive than conventional biofuels" (EurLex 52012PC0595).

Thus, the EC proposal aims at promoting second-generation biofuel technologies that do not use food-competitive raw materials capable of achieving higher greenhouse gas (GHG) emission savings and higher energy efficiency compared to first-generation technologies (Wang et al., 2012). The measures suggested by the EC do not include

* *Corresponding author*. Tel.: +39 0498275468; fax: +39 049 827 5461.
E-mail address: fabrizio.bezzo@unipd.it (F. Bezzo).

Nomenclature

DAP-I	dilute acid prehydrolysis process based on energy crops
DAP-II	dilute acid prehydrolysis process based on agricultural residues
DDGS	dried distilled grains with solubles
DGP	dry grind process
DGP-TS	dry grind process with thin stillage anaerobic digestion
EC	European Commission
GHG	greenhouse gases
LCA	life-cycle analysis
LHV	lower heating value
MILP	mixed integer linear programming
NPV	net present value
WTT	well-to-tank approach for LCA

any financial incentive, but propose to limit the allowed production of first-generation biofuels by creating a new accountability technique to reach the European biofuel production objectives. In fact, first-generation biofuels shall not exceed 50% of total biofuel production and a new categorization of biomasses used for biofuel production is introduced (EurLex 52012PC0595):

(a) bioethanol produced from technologies involving a food-competitive feedstock is accounted "as is" in terms of energy content for the satisfaction of European targets;
(b) bioethanol produced from technologies involving second-generation feedstock from a dedicated culture is accounted twice in terms of energy content with reference to European targets;
(c) bioethanol produced from technologies involving second-generation feedstock from waste materials is accounted four times in terms of energy content with reference to European targets.

This work discusses briefly how the new proposal would affect the configuration of a biofuel (ethanol) production system on a medium term horizon, and demonstrates how process systems engineering techniques and methods can be utilized advantageously to assess the effect of policy proposals and directives in a quantitative way. The optimization of the supply chain layout in northern Italy is taken as a case study. The impact on taxpayers and consumers is also evaluated and compared with the one that would be determined by the current demand scenario.

Three types of plant technologies, corresponding to the three biomass categories in the EC proposal (EurLex 52012PC0595), are included in the model:

(i) Standard dry grind process (DGP): feedstock is corn grain (category (a)); products are ethanol and DDGS, (Kwiatkowski et al., 2006; Franceschin et al., 2008);
(ii) Dilute acid prehydrolysis (DAP-I): feedstock is miscanthus (category (b)); products are ethanol and electricity (Giarola et al., 2012);
(iii) DAP-II: feedstock is corn stover (category (c)); products are ethanol and electricity (Giarola et al., 2012).

Corn grain, miscanthus, and corn stover have been selected respectively for the three plant technologies since they play a major role in the panorama of bioethanol production within the northern Italy domain.

The evolution of feedstock prices is a key issue in the perfor-mance assessment of biofuel supply chains. Some literature studies proposed a stochastic approach to take into account the uncertainty of commodity prices in biorefinery design (*e.g.*, Dal-Mas et al., 2011; Kostin et al., 2012; Gebreslassie et al., 2012; Giarola et al., 2013). Here, the approach proposed by Mazzetto et al. (2013) will be followed and feedstock and products prices will be estimated according to some forecast models based on historical data.

The paper is organized as follows. Section 2 presents and discusses the forecast models to predict price dynam-ics. Section 3 outlines briefly the modeling approach. Section 4 presents and comments the simulation results. Some final remarks conclude the paper.

2. Prediction of commodity prices dynamics

Since the economic performance of a production system depends heavily on the prices of raw materials, utilities, and final products (Manca, 2013a, 2013b), a key aspect in the economic analysis of the bioethanol supply chain in northern Italy is the estimation of the future prices of such goods.

Several works studied the relationships between the prices of commodities used for first-generation biofuels (Yano et al., 2010; Chen et al., 2010; Marzoughi and Kennedy, 2012). Here we adopt a time series decomposition approach (Zarnowitz and Ozyildirim, 2006), which proved to have a very good fit with the historical data (Mazzetto et al., 2013). The same approach was adopted to forecast the ethanol price, which appears to exhibit a similar trend. Thus, the price models are as follows (Mazzetto et al., 2013):

$$\text{Corn Price}_t = (q_{CC} + m_{CC} \cdot t)\left(A_{CC} + B_{CC}\sin\left(\frac{2\pi \cdot t}{T_{CC}} + \varphi_{CC}\right)\right) \quad (1)$$

$$\text{Ethanol Price}_t = (q_{EE} + m_{EE} \cdot t)\left(A_{EE} + B_{EE}\sin\left(\frac{2\pi \cdot t}{T_{EE}} + \varphi_{EE}\right)\right) \quad (2)$$

where m_{CC} [\$/(bu*months)] and q_{CC} [\$/bu] are the parameters of the linear component of the corn price function and q_{EE} [\$/gal] and m_{EE} [\$/(gal*months)] of the ethanol one, while A_{CC} [–], B_{CC} [–], T_{CC} [months] and φ_{CC} [–] are required to define the periodical component of the corn price function, and similarly A_{EE} [–], B_{EE} [–], T_{EE} [months] and φ_{EE} [–] for the ethanol price function. For the sake of clarity, Eqs. (1) and (2) refer to the time series decomposition method that evaluates a time series as the product of a trend function and a periodic function, with the residuals considered as a random contribution.

The parameter values are listed in Table 1 and were obtained by regression on historical U.S.A. average data from 2008 to 2011 (Hofstrand, 2012) and then adapted to the Italian situation (for additional details, see Mazzetto et al., 2013).

The model slightly underestimates real 2012 corn prices (−3.3%) while it has a very good fit on ethanol quotations (+0.4%). The predicted prices for the whole supply chain lifetime are reported in Table 2.

Table 1 – Parameters of the corn and of the ethanol price forecast functions (1) and (2) according to the time series decomposition model.

Parameter	q_{CC}	m_{CC}	A_{CC}	B_{CC}	T_{CC}	φ_{CC}	m_{EE}	m_{EE}	A_{EE}	B_{EE}	T_{EE}	φ_{EE}
Value	3.5874	0.0486	0.9562	0.3057	41.703	1.0926	1.8674	0.0086	0.9728	0.2135	41.692	1.2616

Table 2 – Forecast corn and ethanol prices using the time series decomposition model.

Forecast good	2013–2015	2016–2018	2019–2021	2022–2024	2025–2027
Corn price [€/t]	181	229	286	348	406
Ethanol price [€/kg]	6.32	7.12	8.11	9.21	10.20

In order to assess the effect of the EC proposal, second-generation technologies from dedicated second-generation feedstock and waste material also need to be included in the supply chain model. Miscanthus and corn stover were selected respectively as the most promising energy crop and waste material for bioethanol production. The choice is based on the work developed by Giarola et al. (2012), and on the fact that their cultivation in northern Italy is also recommended by some technical reports (VenetoAgricoltura, 2010).

With concern to miscanthus, no well-established market exists, but rhizome producers (Terravesta, 2012), institutional sources (VenetoAgricoltura, 2010; Teagasc-AFBI, 2010), and biomass experts (Hasings et al., 2011) agree that miscant-hus can be currently sold at about 50 € /t. Medium-term price forecasts are difficult, but a recent study in the UK reported that the breakeven cost of generic energy crops is expected to increase by about +25% by 2020 (Panoutsou and Castillo, 2011). A detailed analysis of the production costs (VenetoAgricoltura, 2010) shows that 50% of the costs are related to yearly expenses, which are mostly due to fertilization (13%), har-vest (26%), and transport inside the farm (61%) and which are essentially related to manpower and oil. If such costs are assumed to grow according to the Italian inflation rate, we obtain a long-term increase, which is consistent with the pre-diction of Panoutsou and Castillo (2011). Thus, the approach was applied to forecast future miscanthus prices as shown in Table 3.

Corn stover is currently priced at about 35 €/t (Euroforaggi, 2012; Camera di Commercio di Forlì-Cesena, 2013). Quite recently, the American Department of Energy (Perlack, 2011) proposed a corn stover supply curve trend until 2030 (Fig. 1) based on US data: it is shown that the supply curve may change in time since an increasing demand will also determine an increase in the corn stover availability. These curves were scaled to the Italian context according to local corn productions (IndexMundi, 2013). It can be inferred that the maximum

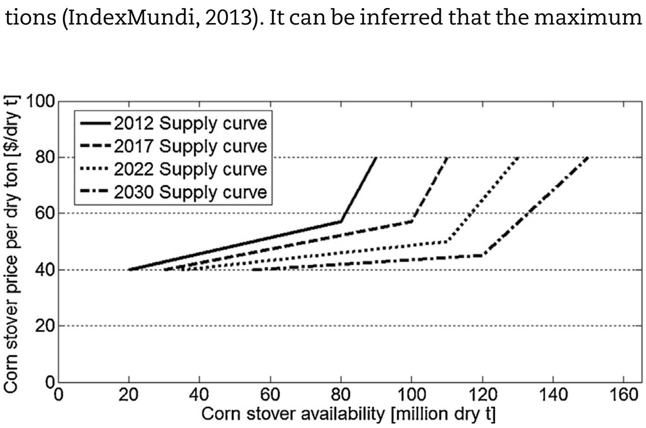


Fig. 1 – Trend of the corn stover supply curve until 2030 in the U.S.A. (adapted from Perlack, 2011).

feasible stover supply (indicated by the change in the slope of the supply curve) is reached if an additional demand of two million dry tons is assumed. Even if the whole bioethanol production in northern Italy were based on corn stover plants, the maximum demand would not exceed 1.7 million dry tons with a price increase of about 12 €/t.

Fig. 1 shows that such a stover demand would cause a significant price increase in 2012. However, the shift in time of the supply curve shows that the demand would have a negligible effect on 2022 stover price and would not cause any price shock on 2030 prices. Therefore, if part of the Italian bioethanol production were satisfied by corn stover, its price would suddenly rise as soon as the supply chain is established, but then increasing supply would compensate for the price shock. This price behavior is summarized in Table 3.

2.1. *Prediction of side-products prices*

Two important side-products are related to the ethanol production processes. Dried distillers grains with soluble (DDGS) and electricity (Kwiatkowski et al., 2006; Balat et al., 2008; Piccolo and Bezzo, 2009). DDGS are used as animal fodder with nutritional properties similar to soybean (Tonsor, 2006) and are obtained from the corn-based DGP technology. In the United States, after the big-scale establishment of the bioethanol supply chain, the DDGS price aligned to the corn one and fluc-tuated between 75% and 110% of the corn price (Hofstrand, 2012). Therefore, it seems reasonable to set the DDGS price as 90% of the corn price also for the Italian context.

Electricity can be produced in combined heat and power modules from combustion of solid wastes from the lignocellulosic biomass (Piccolo and Bezzo, 2009). The electric energy produced by renewable biomasses can benefit from governmental subsidies, whose grant system is currently under renewal (DM 6/7/2012). Nonetheless, experts agree that in mid-term subsidies will lower by around 15% compared to current level (ELEMENS, 2012), and it seems reasonable that this reduction will be confirmed on a ten-year horizon. Table 4 summarizes the forecast prices of by-products.

3. Problem formulation

This paper deals with the strategic design of the economically optimal bioethanol supply chain over a 15-year horizon. This is achieved by maximizing the net present value (NPV) of the whole supply chain during its operative life in a spatially explicit configuration where northern Italy is discretized into 59 grid cells plus one representing the raw material imports. The mathematical formulation in terms of a mixed integer linear programming (MILP) framework is based on the work

Table 3 – Forecast miscanthus and corn stover prices by period.

	2013–2015	2016–2018	2019–2021	2022–2024	2025–2027
Forecast miscanthus price [€/t]	50.50	54.10	58.50	63.20	68.40
Forecast corn stover price [€/t]	40	40	35	35	35

Table 4 – Forecast prices of by-products by time period.

	2013–2015	2016–2018	2019–2021	2022–2024	2025–2027
Forecast DDGS price [€/t]	163	206	257	313	365
Forecast electricity price [€/MWh]	200	170	170	170	150

of Giarola et al. (2011). The supply chain layout is obtained by optimizing:

(i) geographical location of biomass production sites;
(ii) biomass production for each site;
(iii) supply strategy for biomass to be delivered to production facilities;
(iv) biofuel production facilities location and scale;
(v) distribution processes for biofuel to be sent to blending terminals

in order to maximize the supply chain NPV.

The environmental impact of the supply chain in terms of GHG emission is estimated as in Zamboni et al. (2009) according to IPCC (2001) directives, by assessing the impact of LCA stages, *i.e.* biomass growth, biomass pre-treatment, biomass transport, fuel production and fuel distribution. A well-to-tank (WTT) approach is assumed. In addition, emission credits (*i.e.* GHG emission savings as a result of goods or energy displacement by process by-products end-use) are accounted for. The GHG impact on global warming is captured by a whole set of burdens (CO_2, CH_4, N_2O). They have been grouped together in a single indicator representing the carbon dioxide equivalent emissions (CO_2-eq) as derived through the concept of 100-year global warming potentials.

Ethanol demand is forecast assuming that gasoline and diesel should reach the targets set by the Directive separately, starting from a negligible ethanol production in Italy in 2012 (USDA Foreign Agricultural Service, 2011). Therefore, it is supposed that the ethanol blending rate in 2013 is the one fixed by the Directive as the starting point in 2010, *i.e.* 5.75% on energy basis. Consequently, the increasing trend in the substitution quota is extended until 2027 in order to anticipate further regu-lations and to take into account the starting delay in achieving the targets (11.5% on energy basis from 2023).

Since the technologies discussed in this work exhibit significant differences in their maturity, it was assumed to limit the maximum capacity of second-generation production plants to 110 kt/y (representing the size of largest planned conversion facilities). Conversely corn-based plants were assumed to reach a production capacity up to 350 kt/y (which is about the size of largest existing plants, see also Mazzetto et al., 2013).

4. Results

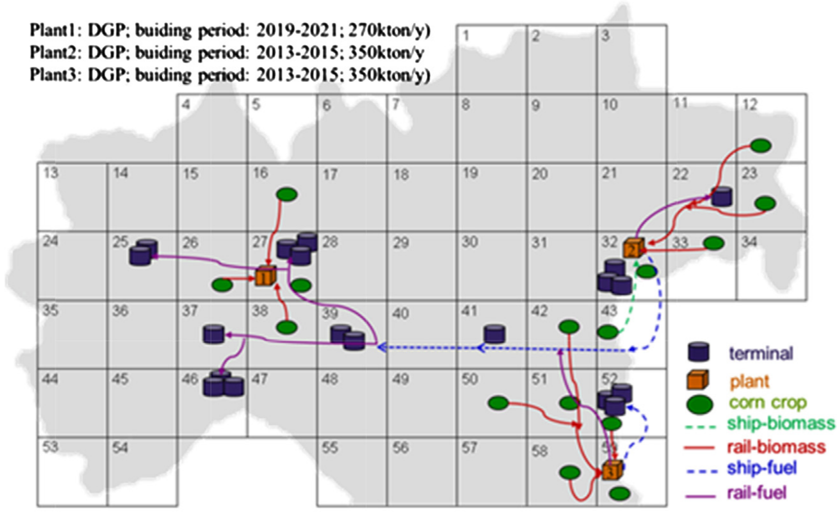
The supply chain model has been optimized taking into account the existing EU regulation (Scenario I) and the new EC proposal (Scenario II). It is assumed that production targets (calculated as is or as per the EC proposal) need to be satisfied.

The new proposal has a strong influence on the profitability of the supply chain, since economic losses are reduced by 27%compared to the optimal supply chain defined by the existing legislation. In fact, although a negative NPV is still obtained (−594 M€), the economic losses are significantly lower than the ones obtained with current configuration (−815 M€). This is simply achieved by producing less ethanol, thanks to the multiplicative effect assigned to second-generation ethanol. According to Scenario I, at the end of time horizon, the 970 kt/y ethanol production would be satisfied by first-generation DGP technology, whereas the new EC proposal would lead to a reduced capacity of 520 kt/y satisfied by both first and second-generation technologies. Notably, the ethanol production in the simulation of the EC proposal would not comply with the production targets of the current directive as the new multi-plicative factors allow producing less ethanol and still "satisfy" the targets. In other words, in case of a non-profitable business (as this one), the EC proposal would allow producing less (and therefore losing less money). Table 5 shows the actual ethanol production (represented as percentage) with respect to target quotas.

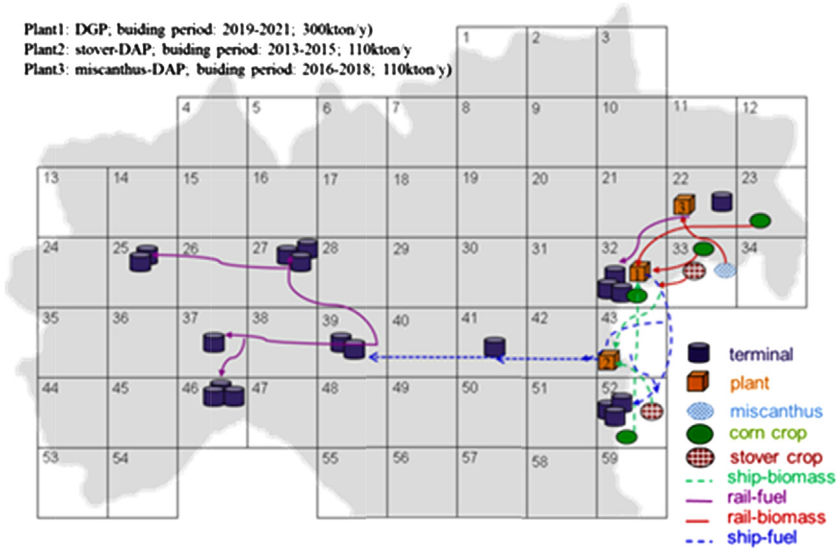
As illustrated in Fig. 2, both scenarios determine the eventual establishment of three plants. The effect of current policies is represented in Fig. 2a, while Fig. 2b shows the final supply chain layout of Scenario II. In the latter case (Fig. 2b), two 110 kt/y second-generation plants (*i.e.* stover-based and miscanthus-based), and a 300 kt/y first-generation DGP plant would be required, while in Scenario I (Fig. 2a) three DGP plants would be built, two of them producing 350 kt/y and the remain-der 270 kt/y. As intended, a result of the EC proposal appears to be that of promoting second-generation technologies.

The reduction of the ethanol content in the blended fuel does not reduce its overall sustainability. Scenario II determines that the ethanol-related CO_2-emissions are halved (36.9 $kgCO_2$-equivalent/GJ of ethanol) with respect to Scenario I (73.2 $kgCO_2$-equivalent/GJ of ethanol). However, the lower production determines that less bioethanol is blended with gasoline. As a consequence, the emissions of the blended fuel are reduced by about 3% only (81.1 $kgCO_2$-equivalent/GJ fuel with the EC proposal *vs.* 82.7 $kgCO_2$-equivalent/GJ fuel with the current regulation). In other words, although the EC proposal appears to promote second-generation technologies, its impact on fuel GHG emissions is hardly significant and obviously it deteriorates the security for transport energy since a lower amount of alternative fuels would be produced.

In order to verify that the resulting scenarios are not affected by the price prediction models, the optimization problem has been studied also considering fixed feedstock and ethanol prices. The prices were set as the average real quotations of the commodities in the last three years (182 €/t for



(a)



(b)

Fig. 2 – Optimal supply chain layout under the existing Directive (Scenario I) at the end of the time horizon (time period 2025–2027) (a); optimal supply chain layout with the EC proposal (Scenario II) at the end of the time horizon (b).

corn, 5.75 €/kg for ethanol, 50 €/t for miscanthus and 35 €/t for corn stover). The resulting supply chain was nearly identical in terms of adopted technologies and general layout as the ones at variable prices, which is very encouraging about the robustness of the supply chain design, because it proves that the results are not dependent on the chosen price prediction model. The main differences concerned the estimated profitability of the supply chain. In case of Scenario I a 5% increase in the NPV is obtained, simply because there is not a significant increase in the corn price as on the contrary predicted by the forecast model. Conversely, the NPV of Scenario II deteriorates by about 18% with respect to the case where price dynamics is accounted for (mainly because the predicted growth in ethanol price is not considered), but still outperforms Scenario I.

4.1. *Impact on consumers and taxpayers*

Since the ethanol supply chain is predicted to be unprofitable, losses should be either transferred to final customers or compensated for by governmental subsidies (as was done in the United States until 2011). If the latter case is assumed, Table 6 shows the calculated governmental subsidies per period and their equivalent amount in current terms. The comparison with subsidies that should be granted with the current legislation shows that a reduction by 56% would be obtained thanks to the recent EC proposal. Table 6 also shows a potential benefit of the EC proposal. Although quantitative results depend on models for price forecast, it appears that in Scenario II, subsidies would be needed in the initial operation period only (*i.e.* for about 5 years), when losses occur. Conversely, in the

Table 5 – Production fulfillments of the current ethanol demand (referring to the existing Directive) in case the EC proposal was put into effect.

	2013–2015	2016–2018	2019–2021	2022–2024	2025–2027
Demand fulfillment (%)	42	38	44	50	55

Table 6 – Bioethanol supply chain losses per time period and over the whole horizon in current terms. For Scenario II, in periods 2019–2021, 2022–2024, and 2025–2027 the 0 value denotes that there are no losses (in fact, the supply chain is profitable).

	2013–2015	2016–2018	2019–2021	2022–2024	2025–2027	Total equivalent in current terms[a] [M€]
Supply chain losses in Scenario I [M€]	379	211	359	506	706	1507
Supply chain losses in Scenario II [M€]	506	198	0	0	0	670

[a] Discounted at the 15-year Italian bond rate.

Table 7 – Expected total fuel prices and fuel prices at equivalent mileage in the case with or without EC proposal (Gasoline price assumed to be constant at 1.785 €/L).

	2013–2015	2016–2018	2019–2021	2022–2024	2025–2027
Total fuel price with the EC proposal [€/L]	1.77	1.76	1.75	1.76	1.77
Total fuel price with current regulation [€/L]	1.73	1.72	1.74	1.76	1.78
Total fuel price difference	+2.4%	+2.0%	+0.7%	0.0%	−0.9%
Total fuel price at equivalent mileage with the EC proposal [€/L]	1.80	1.79	1.79	1.80	1.82
Total fuel price at equivalent mileage with current regulation [€/L]	1.78	1.78	1.80	1.83	1.86
Total fuel price at equivalent mileage difference	+1.1%	+0.5%	−0.7%	−1.5%	−2.3%

current state of things (Scenario I) government intervention seems necessary along the entire business activity.

If losses were repaid by fuel consumers, the blended fuel price would be composed of:

(i) Gasoline price plus taxes weighted on the volume fraction of gasoline;
(ii) Ethanol price plus VAT (22% in Italy) and the per-liter losses repayment.

If the gasoline price is assumed to remain constant at the 2012 average Italian price (1.785 €/L according to Ministero dello sviluppo economico, 2013), the fuel prices with the EC proposal would be more expensive at the beginning (because of the very high capital costs of second-generation plants), but then they would be cheaper by about 1% compared with the ones obtained with current legislation.

Nevertheless, it is worth remembering that the blended fuel has a lower heating value (LHV) that is inferior to that of normal gasoline, since ethanol LHV is about 65% of the gasoline one. Table 7 reports the comparison both on the “pump price” and at equivalent mileage, which is most meaningful. It can be seen that the EC proposal would guarantee after 2019 a cheaper fuel up to 2.3%.

5. Conclusions

A recent European Commission proposal on the promotion of the use of energy from renewable sources, which amends both Directives 98/70/EC and 2009/28/EC, has been critically analyzed with concern to its effects on the design of bioethanol supply chains. The economic optimization based on a MILP model of the supply chain showed that the proposal can promote the establishment of a bioethanol supply chain, where lignocellulosic biomasses are extensively used in the production processes. However, since a possible consequence would be a lower ethanol production, the advantages in terms of reduction of GHG emissions would be hardly significant and there would be deterioration in energy security for transport. On the other hand, probable economic losses would be less aggravating, and accordingly the burden either on final fuel consumers or on governmental incentives would decrease. The authors consider this approach innovative and of critical importance to limit the use of alimentary competitive feedstock, thus giving a concrete contribution to the debate on biofuels ethics. Nevertheless, the energy security principles on which the biofuels production is based cannot be altered; therefore, it can be advisable to maintain the maximum production quota for first generation biofuels, and to decrease the multiplying coefficients for advanced biofuels. This solu-tion would also allow increasing the environmental benefits of the European Commission proposal, since a larger share of the blended fuel would be composed of low-pollutant fuels. While this option could engender worse economic configurations of the supply chain than those based on the current values, it is possible to arrange the multiplying coefficients of second generation technologies so that the new supply chain would still be more profitable than the one based on current legislation. In fact, the coefficient values can be chosen in a number of ways, since there are no constraints on either of them. In this perspective, the European Parliament has recently subscribed a call on the Commission (Europarl, 2013) to amend the factors in the original proposal, thus asking for a modification of the accountability technique to reach the European biofuel production objectives as required by the legislative procedure (EurLex C 115/47, 2008). Notably in the proposed amendment, the Parliament appears to endorse bioethanol production from dedicated cultures (where a $\times 2$ accountability method would be maintained), whereas waste materials such as straw (or corn stover) would be somewhat penalized being accounted just once as occurs for first generation technologies. A high multiplicative factor ($\times 4$) would be retained only for highly advanced (and not quite mature) technologies such as algae-based fuel production systems. Our interpretation is that, according to the EU Parliament, promotion policies should be directed either toward the more mature second gen-eration technologies, which are based on dedicated cultures and have already demonstrated a high capacity potential (*e.g.*, see Biochemtex, 2013), or toward high-risk groundbreaking processing technologies.

References

Balat, M., Balat, H., Oz, C., 2008. Progress in bioethanol processing. Prog. Energy Combust. Sci. 34, 551–573. Biochemtex, 2013. A New Era Begins Crescentino World's First Advanced Biofuels Facility, Available from: http://www.biofuelstp.eu/presentations/crescentino-presentation.pdf

Camera di Commercio di Forlì-Cesena, 2013. Listino prezzi paglia di mais, Available from: http://www.fc.camcom.it/prezzi/listino/prodotti/prodotto.jsp?id=1343 (last accessed March 2013).

Chen, S.T., Kuo, H., Chen, C.C., 2010. Modeling the relationship between oil price and global food price. Appl. Energy 87, 2517–2525.

Dal-Mas, M., Giarola, S., Zamboni, A., Bezzo, F., 2011. Strategic design and investment capacity planning of the ethanol supply chain under price uncertainty. Biomass Bioenergy 35, 2059–2071.

ELEMENS, 2012. Rinnovabili elettriche Analisi del DM 6 luglio 2012, Available from: http://www.lmns.it/wp-content/uploads/2012/07/casaclima.com-13 07 20121.pdf (last accessed January 2013).

EurLex 52012PC0595 – Proposal for a directive of the European parliament and of the council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Available from: http://eur-lex.europa.eu/LexUriServ (last accessed October 2013).

EurLex C 115/47, 2008. Treaty on the Functioning of the European Union, Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2008:115:0047:0199:EN:PDF

Euroforaggi, 2012. Pellet di paglia e stocchi di mais presso Bagioni group, Available from: http://www.mixbiopells.eu/fileadmin/user_upload/WP3/Best practices transl/Italian/Best_practice_pelletising CTI IT.pdf (last accessed January 2013).

Europarl, 2013. P7_TA-PROV(2013)0357, European Parliament legislative resolution of 11 September 2013 on the proposal for a directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (COM(2012)0595 – C7-0337/2012 – 2012/0288(COD)), Available from: http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P7-TA-2013-0357+0+DOC+XML+V0//EN&language=EN

Farrell, A., Plevin, R., Turner, B., Jones, A., O'Hare, M., Kammen, D., 2006. Ethanol can contribute to energy and environmental goals. Science 311, 506–508.

Franceschin, G., Zamboni, A., Bezzo, F., Bertucco, A., 2008. Ethanol from corn: a technical and economical assessment based on different scenarios. Chem. Eng. Res. Des. 86, 488–498.

Gebreslassie, B.H., Yao, Y., You, F., 2012. Design under uncertainty of hydrocarbon biorefinery supply chains: multiobjective stochastic programming models, decomposition algorithm, and a comparison between CVaR and downside risk. AIChE J. 58, 2155–2179.

Giarola, S., Bezzo, F., Shah, N., 2013. A risk management approach to the economic and environmental strategic design of ethanol supply chains. Biomass Bioenergy 58, 31–51.

Giarola, S., Shah, N., Bezzo, F., 2012. A comprehensive approach to the design of ethanol supply chains including carbon trading effects. Bioresour. Technol. 107, 175–185.

Giarola, S., Zamboni, A., Bezzo, F., 2011. Spatially explicit multi-objective optimisation for design and planning of hybrid first and second generation biorefineries. Comput. Chem. Eng. 35, 1782–1797.

Gomiero, T., Paoletti, M.G., Pimentel, D., 2010. Biofuels: efficiency, ethics, and limits to human appropriation of ecosystem services. J. Agric. Environ. Eth. 23, 403–434.

Hasings, A., Sunnenberg, G., Lovett, A., Finch, J., Wang, S., Hillier, J., Smith, P., 2011. Spatial Mapping and Evaluation of Miscanthus Crop Distribution in Great Britain to 2050, Available from: http://www.carbo-biocrop.ac.uk/uploads/Hastings_miscanthus%20yields_UKERC.pdf (last accessed January 2013).

Hofstrand, D., 2012. d1–10ethanolprofitability.xls, Available from: https://www.extension.iastate.edu/agdm/energy/html/d1-10.html (last accessed January 2013).

IndexMundi, 2013. Corn Production by Year, Available from: http://www.indexmundi.com (last accessed January 2013).

Intergovernmental Panel on Climate Change (IPCC), 2001. In: Houghton, J.T., Ding, Y.,Griggs, D.J., Noguer, M., van der Linden, P.J.,Dai, X., Maskell, K., Johnson, C.A. (Eds.), Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, UK.

Kostin, A.M., Guillén-Gosálbez, G., Mele, F.D., Bagajewicz, M.J., Jiménez, L., 2012. Design and planning of infrastructures for bioethanol and sugar production under demand uncertainty. Chem. Eng. Res. Des. 90, 359–376.

Kwiatkowski, J., McAloon, A., Taylor, F., Johnston, D., 2006. Modeling the process and costs of fuel ethanol production by the corn dry-grind process. Ind. Crop. Prod. 23, 288–296. Manca, D., 2013a. Modeling the commodity fluctuations of OPEX terms. Comput. Chem. Eng. 57, 3–9.

Manca, D., 2013b. A methodology to forecast the price of electric energy. Comput. Aid. Chem. Eng. 32, 679–684.

Marzoughi, H., Kennedy, P.L., 2012. The Impact of Ethanol Production on the U.S. Gasoline Market, Southern Agricultural Economics Association Annual Meeting, Birmingham.

Mazzetto, F., Ortiz-Gutierrez, R.A., Manca, D., Bezzo, F., 2013. Strategic design of bioethanol supply chain including commodity market dynamics. Ind. Eng. Chem. Res. 52, 10305–10316.

Ministero dello sviluppo economico, 2013. Prezzi medi nazionali 2012 – Benzina senza piombo, Available from: http://dgerm.sviluppoeconomico.gov.it/dgerm/prezzimedi.asp?prodcod=1&anno=2012

Panoutsou, C., Castillo, A., 2011. Outlook on Market Segments for Biomass Uptake by 2020 in the UK, Biomass Futures.

Perlack, B., 2011. 2011 Feedstocks Review Supply Forecast & Analysis. Oak Ridge National Laboratory.

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

Renewable Fuels Association, 2012. Ethanol Facts: Energy Security, Available from: http://www.ethanolrfa.org/pages/ethanol-facts-energy-security (last accessed January 2013).

Teagasc-AFBI, 2010. Miscanthus Best Practice Guidelines.

Tenenbaum, D.J., 2008. Food vs. fuel: diversion of crops could cause more hunger. Environ. Health Perspect. 116, 254–257.

Terravesta, 2012. Miscanthus Crop Establishment, Lincoln, UK, Terravesta.

Tonsor, G.T., 2006. Feed Cost Savings of Dried Distillers Grains in Finishing Hog Rations. Michigan State University.

USDA Foreign Agricultural Service, 2011. EU-27 Annual Biofuels Report, The Hague.

VenetoAgricoltura, 2010. Colture Energetiche per il disinquinamento della laguna di Venezia – progetto BioColt, Available from: www.venetoagricoltura.org/upload/. . ./Progetto%20Biocolt/Cap%202.pdf (last accessed March 2013).

Wang, M., Han, J., Dunn, J., Cai, H., Elgowainy, A., 2012. Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. Environ. Res. Lett. 7, 1–13.

Yano, Y., Blandford, D., Surry, Y., 2010. The Impact of Feedstock Supply and Petroleum Price Variability on Domestic Biofuel and Feedstock Markets – The Case of the United States. Swedish Department of Agricultural Sciences.

Zamboni, A., Bezzo, F., Shah, N., 2009. Spatially explicit static model for the strategic design of future bioethanol production systems. 2. Multi-objective environmental optimization. Energy Fuels 23, 5134–5143.

Zarnowitz, V., Ozyildirim, A., 2006. Time series decomposition and measurement of business cycles, trends and growth cycles. J. Monet. Econ. 53, 1717–1739.