UNIVERSITÀ DEGLI STUDI DI PADOVA

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

CORSO DI LAUREA MAGISTRALE IN INGEGNERIA CHIMICA E DEI PROCESSI INDUSTRIALI

Tesi di Laurea Magistrale in
Ingegneria Chimica e dei Processi Industriali

DESIGN OF BIOETHANOL SUPPLY CHAINS INCLUDING COMMODITY MARKET DYNAMICS AND MULTIPLE DEMAND SCENARIOS.

Relatore: Prof. Fabrizio Bezzo
Correlatore: Prof. Davide Manca

Laureando: Filippo Mazzetto

ANNO ACCADEMICO 2012−2013

Abstract

Biofuels blending with fossil ones is mandatory according to European Directives. Bioethanol is the most used biofuel in some countries of the world (e.g. U.S.A., Brazil) but it is still not widespread in Italy. The establishment of a bioethanol supply chain in northern Italy will be simulated in this work by evaluating its spatial explicit layout, the used technologies for ethanol production, biomass production sites, transport network and its financial performance. The economic details are based on the forecasted price dynamics of all the commodities related to ethanol production. Four price forecast models will be compared in order to assess the supply chain robustness to changes in price evolution dynamics, so that the risk for investors is mitigated.

Furthermore, the optimal supply chain layout according to the European Commission proposal amending the existing Directive on ethanol blending will be presented. The economic impact on taxpayers and fuel consumers of the proposed modifications will also be assessed.

This work will prove that the bioethanol supply chain is not a profitable investment, whatever the commodity prices evolution path. Nevertheless, the optimal supply chain layout does not significantly changes with alternative price evolution dynamics. Italian customers will benefit of cheaper fuel even if they had to repay for the supply chain losses; furthermore the obtained fuel would have an appreciable buffer effect on gasoline price shocks.

The European Commission proposal effectively promotes the recourse to second−generation ethanol (i.e. more sustainable one). The overall economic performance is still negative, but significant improvements compared to the current demand scenario are registered. The bioethanol supply chain based on agricultural residuals (e.g. corn stover) presents interesting economic features, too. The reduced quantity of bioethanol in the blended fuel, according to this proposal, makes the final price more dependent on gasoline price, therefore the energy security effect of biofuels is seriously questioned.

Riassunto

Il lavoro di tesi magistrale si concentra sulla pianificazione della filiera produttiva del bioetanolo, inteso come biocarburante additivo alla benzina per autotrazione. Nell'ottemperanza delle direttive comunitarie, l'Italia deve raggiungere delle quote predefinite di biocarburanti nel combustibile venduto, è perciò necessario l'instaurarsi di una filiera produttiva di bioetanolo, uno dei principali biocombustibili, nel Nord Italia.

Un modello di programmazione lineare mista a variabili intere (MILP) è stato utilizzato come strumento di ottimizzazione della filiera per definire la collocazione esatta di impianti e la loro capacità produttiva, i luoghi di approvvigionamento della biomassa e la rete di trasporti necessaria tanto per le materie prime quanto per il bioetanolo. L'obiettivo è di configurare la supply chain che registri le prestazioni economiche ottimali.

Per far ciò si sono studiati i prezzi di tutti i beni legati alla produzione di etanolo con le tecnologie più mature e consone alle latitudini di applicazione, ovvero prendendo a modello la filiera instauratasi negli Stati Uniti a partire dal mais come materia prima. Nel modello sono state incluse anche delle tecnologie sperimentali considerate particolarmente promettenti, anch'esse basate sul mais, ovvero quelle che fanno ricorso a un modulo di fermentazione per la cogenerazione di biogas.

Sono stati valutati quattro metodi diversi di predizione del prezzo delle materie prime e dei prodotti dei processi produttivi di bioetanolo, poiché l'obiettivo del presente lavoro era di descrivere con la maggior precisione possibile la redditività economica della filiera. Dei quattro metodi, due legano il prezzo di etanolo e mais a quello di un bene di riferimento (petrolio) che è indipendentemente studiato in maniera stocastica, mentre altri due procedono basandosi esclusivamente sulle serie storiche dei prezzi di ciascun bene. In particolare, un modello applica un approccio stocastico alle quotazioni dei beni stessi, basandosi sulle variazioni relative storiche dei prezzi, mentre l'altro modello scompone l'andamento dei prezzi di mais e etanolo mediante due funzioni distinte, una funzione lineare crescente e una periodica di tipo sinusoidale. I parametri di tutti i modelli sono stati regrediti a partire dai valori registrati negli Stati Uniti dopo l'instaurazione di una filiera produttiva equivalente. Si noti che tutti i modelli studiati hanno permesso di ottenere una stima dei prezzi con un intervallo d'errore accettabile rispetto alle vere quotazioni medie dell'anno 2012. I prezzi dei sottoprodotti dei processi sono stati anche stimati, sempre a partire da studi storici della situazione americana (per i DDGS, dei validi mangimi per animali) o da recenti analisi (per l'energia elettrica ottenuta da impianti con moduli di cogenerazione).

Grazie a ciò, è stato possibile pianificare con l'accuratezza che nessun lavoro precedente aveva toccato, la filiera produttiva che presentasse le migliori prestazioni economiche in

ciascuno dei casi di predizione dei prezzi. Facendo ciò, è stato possibile verificare la robustezza della supply chain ai cambiamenti nell'evoluzione dei prezzi negli anni a seguire, ovvero si voleva dimostrare che qualsiasi andamento i prezzi avessero avuto, l'ubicazione di impianti e zone di coltura rispettava sempre l'ottimalità economica; ciò permette di ridurre sensibilmente il rischio per gli investitori, che sarebbero sempre sicuri di aver scelto il miglior investimento possibile. Rispettando la legislazione attuale, la supply chain che si andrebbe a costituire sarebbe un investimento non redditizio secondo qualunque modello di evoluzione dei prezzi delle commodities legate al processo produttivo. Questo non è un risultato sorprendente se confrontato con le notizie di non redditività per l'anno 2012 degli impianti di bioetanolo negli Stati Uniti, dove tale filiera produttiva è consolidata da quasi una decina d'anni. Ciononostante si può verificare che le dislocazioni geografiche ottimali degli impianti e le loro tecnologie di produzione restano sostanzialmente inalterate al variare dei modelli di previsione dei prezzi.
Successivamente sono stati discussi gli impatti economici della realizzazione di tale filiera sia sui cittadini che sui consumatori finali di combustibili per auto e in particolare è stato previsto l'impatto sul prezzo del combustibile che risulterà dall'additivazione del bioetanolo con la benzina. I consumatori finali otterranno un carburante il cui prezzo è generalmente allineato con quello della benzina pura oppure meno costoso di essa, anche qualora le perdite della filiera produttiva fossero incluse nel prezzo finale.
Nell'ultimo capitolo si è studiato l'impatto della proposta di modifica all'esistente direttiva sui biocombustibili pubblicata recentemente della Commissione Europea. In particolare, si è confrontata la supply chain ottimale in tale configurazione con quella prevista dallo scenario legislativo attuale. È parso adeguato confrontare l'impatto sul prezzo del combustibile e nell'ottica della sicurezza energetica di una filiera produttiva aderente a questa proposta.
Le modifiche alla Direttiva esistente proposte dalla Commissione Europea sono efficaci nel promuovere il ricorso a bioetanolo di seconda generazione. Infatti, nel caso esse entrino in vigore, la supply chain ottimale si baserebbe su un impianto alimentato a miscanto affiancato da uno tradizionale a mais, con prestazioni economiche complessive della filiera sostanzialmente migliori che nel caso corrente. Anche la filiera basata su scarti agroalimentari (per esempio, stocchi di mais) dimostra performance interessanti.
In tal caso, però, il combustibile finale conterrebbe una minor quantità di bioetanolo cosicché il ruolo principale dei biocarburanti, ovvero di autosufficienza energetica, sarebbe messo seriamente in discussione.

Table of contents

Chapter 1

Context and previous works

In this chapter biofuel production is presented in the context of the global energy issues and notably under the European Union perspective. The main industrial production processes are briefly illustrated. The bioethanol supply chain design is then detailed under its mathematical formulation developed by previous works, whose results are also presented. Finally, the motivations for this work are outlined.

1.1 Biofuels and energy issues

1.1.1 Global energy context and the role of biofuels

Despite the recent financial crisis (2008 and 2012), global energy demand has not halted, mainly because high growing rates of the most energy−intensive economies, such as China and India (Bloomberg, 2013). The increase in energy consumption goes along with the increase in greenhouse gases (GHG), mostly carbon dioxide. Transport sector is the fastest growing consumer of energy and producer of greenhouse gases in Europe (European Commission Eurostat, 2006) and the second sector by final energy consumption in the U.S.A. and in the whole world with a share of respectively 28% and 27% (EIA, 2012). The whole energy consumption of the transport sector comes from petroleum, whose production is concentrated in few areas around the world. The oligopoly represented by OPEC and few other countries replaced the "Seven sisters" in the 70s and controls most of oil production (and therefore its price). Those countries are also known for their political instability, so oil price registers high volatility and energy security arose as a major topic in political debate. Transport sector is critical also because of the very high requirements in energy content per volume of the energy sources used, that gives little room to present−day substitutes like hydrogen or electricity.
The United States reacted strongly to these issues by approving in 2005 the Energy Policy Act, which included mandatory energy conservation standards and energy efficiency tax credits for many pieces of equipment but, more importantly, tax credits and abundant subsidies for biodiesel and bioethanol producers. Biodiesel and bioethanol are fuels that can be added respectively to diesel and gasoline which are obtained from biomasses instead of non−renewable resources. The logic behind that is to consistently replace part of crude oil

import by American−produced fuel. In addition to that, many States banned the use of MTBE as an addictive to gasoline to increase the octane rating for environmental concerns, and ethanol proved to be an excellent substitute: in fact pure ethanol RON (Research Octane Number: higher values indicate higher fuel resistance to pre−ignition) rating is 113, while currently sold unleaded gasoline’s RON is between 91 and 95. The main raw material for ethanol production in the U.S.A. is corn, whose the U.S.A. are world leader producer. Furthermore, corn−ethanol proved to have a positive energy balance (that is it provides more energy than the one needed for producing it) and produces slightly less GHG (GreenHouse Gases) than gasoline (−7%) even if this last point is controversial (Farrell et al., 2006), although the carbon dioxide emitted from ethanol burning comes from renewable sources (Chandel et al., 2007). What is sure is that American oil imports from the Persian Gulf region reduced by 25% since 2005 and foreign oil dependence was reduced from 60% to 50% in the same period (Congressional Research Service, 2011). This led to the fact that in States where the ethanol blending rate with gasoline was higher, the impact of the skyrocketing oil prices on gasoline consumers was diminished by 10%−15%, that is pump price was 0.29 c$/gal−0.40 c$/gal less than it would otherwise have been (Du and Hayes, 2008). Globally, more than 480 million barrels of oil were prevented from importing in 2011 thanks to ethanol blending with gasoline, as shown in figure 1.1 (Renewable Fuels Association, 2012).

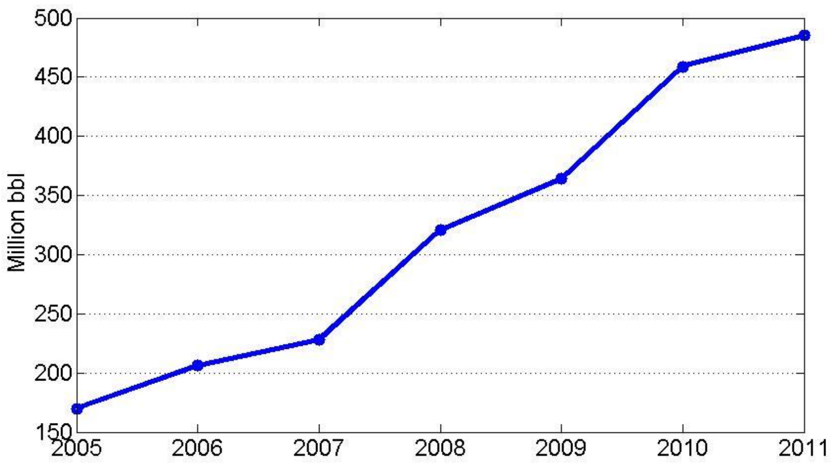

Figure 1. 1. *Historical oil import displacement by ethanol in the U.S. (elaborated from Renewable Fuels Association, 2012)*

1.1.2 Current European regulation

Europe has an even worse commercial balance for hydrocarbons than the United States, because it has very little petroleum resources and therefore the dependence on Middle East oil policies is greater. For this reason, the European Union set up a regulation on biofuels even before the U.S.A., with the approval of Directive 2003/30/EC in 2003. On the other hand, the directive had to be converted into law by each Country, so it took effect starting from 2008 only. The objective was to reach 5.75% biofuel blending by 2010, which is approximately half of the American blending rate. That is due to the fact that Europe has not the same agricultural resources of the U.S.A., and therefore is not able to produce as much biofuels; and also because no subsides nor tax credits was granted to biofuels producers or blenders; instead, a mandatory blending rate was imposed to member countries.

The Directive was revised in 2009 (Directive 2009/28/EC) and was converted into law in the following years by the member states: Italy did that through the D.Lgs 28 of 3/3/2011. This directive sets the targets for biofuel blending until 2020 and includes a first definition of Indirect Land Use Changes, that is a system to take into account the change in land use due to ethanol production that is not directly linked to ethanol facilities. Other directives are currently under study; further details are reported in chapter 4.

1.2 Bioethanol production processes

1.2.1 First generation bioethanol production processes

Bioethanol is the most used biofuel around the world. It can be obtained from biomass according to two types of technologies:

(i) First generation ones, which use biomasses rich in simple sugars, starch or oil: their production process is generally well established; however, one key issue is that raw materials are often used for alimentary purposes, too;

(ii) Second generation ones, that use lignocellulosic materials and therefore do not compete directly with alimentary crops: technology is not at the industrial scale yet, but they are considered the real sustainable alternative to fossil fuels.

The present work focuses mainly on first generation technology, because it is already available on industrial scale and its know−how is widespread. An overview on second generation technologies is presented in chapter 4, where the supply chain design is simulated including also second generation plants.

First generation bioethanol is produced from fermentation of simple sugars: the process has similarities with the alcoholic beverage processes, but it is pushed to obtain fuel−grade ethanol, that is pure at 99.8% and other valuable by−products to improve the economic performance. The main biomasses for corn production are corn (in the U.S.A.), sugarcane (in Brazil) and sugar beet in Europe. Here attention is focused on the process for bioethanol from corn, which is the most economical type of process on industrial scale at the European latitudes.

The most used process from corn is the Dry Grind Process, that produces ethanol as well as Dried Distilled Grains with Solubles (DDGS), which is valuable animal fodder.
Figure 1.2 reports the block diagram of the process (Franceschin et al., 2008), from which five sections can be distinguished:

- (i) Grinding, cooking and liquefaction
- (ii) Saccharification and fermentation
- (iii) Distillation and dehydration
- (iv) Water evaporation and recycling
- (v) Drying of the non−fermentable fraction

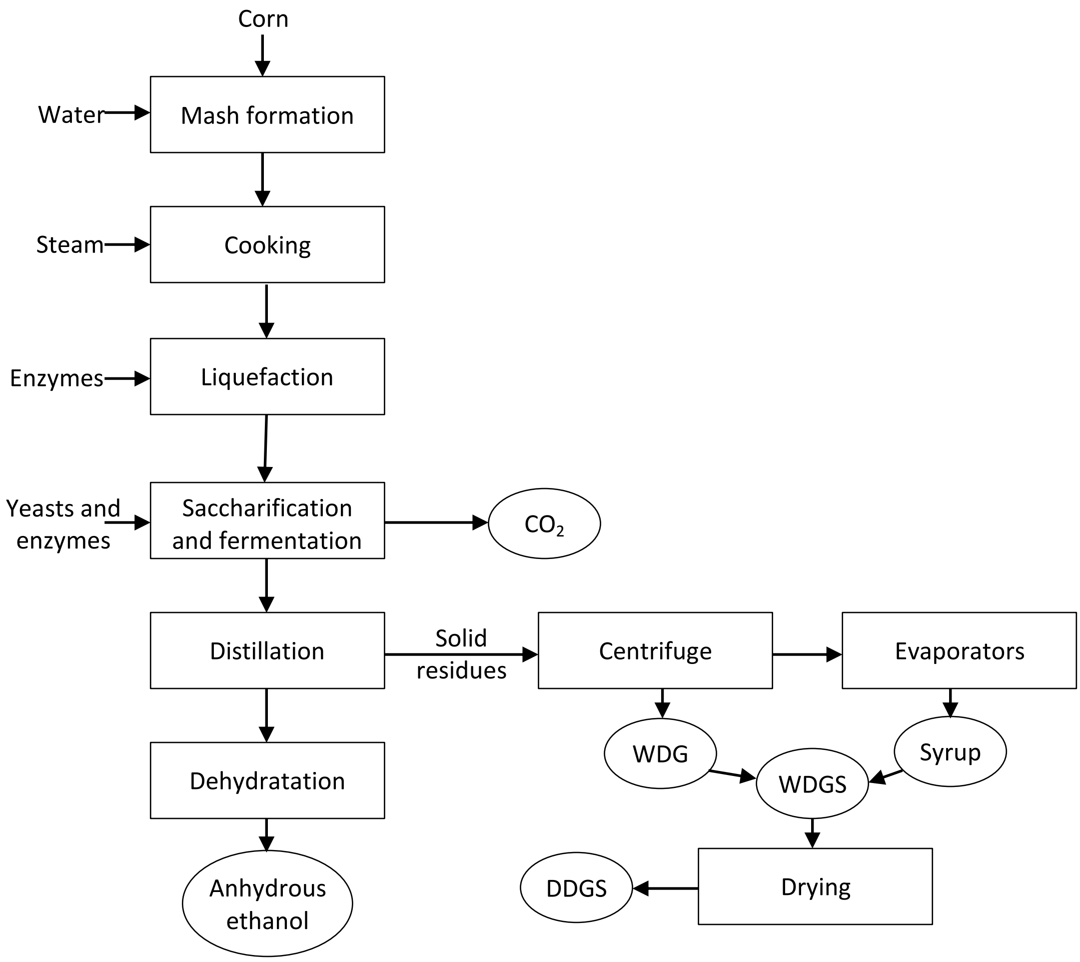

Figure 1. 2. *Block diagram of the ethanol Dry Grind Process from corn (from Franceschin et al, 2008)*

In the first plant section, the corn is milled down to the proper particle size (<2mm) in order to facilitate the subsequent penetration of water and is sent to a slurry tank together with process water. The slurry is "cooked" by using steam at 4 bar: the process temperature (110 °C) allows the sterilization of the slurry and breaks the starch hydrogen bonds so that water can be absorbed. This step is termed "gelatinization" because the resulting mixture has a highly viscous, gelatinous consistency. The following liquefaction step (85 °C) is accomplished by the action of α−amylase enzyme on the exposed starch molecules. α−Amylase is added at 0.082% (dry basis with respect to corn, db): the effect is a random breakage of the α−1,4 glucosidic amylose and amylopectin linkages, thus decreasing the viscosity. The mash from the liquefaction vessel is added to a backset stream and cooled down to 35 °C, ready for the fermentation step.

In the fermentation reactor, a simultaneous saccharification and fermentation (SSF) occurs: starch oligosaccharides are almost completely hydrolyzed (99%) into glucose molecules by glucoamylase enzyme (added at 0.11% db) and the yeasts (Saccharomyces cerevisiae) catalyze the reaction of "fermentation" described by following equation.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad , \qquad (1.\ 1)$$

giving a "beer", whose ethanol content is about 12% w/w, that is sent to the distillation section. Usually three distillation columns at different pressure conditions are used: this is designed to obtain a 92% w/w ethanol purity in the distillate, so that a molecular sieve section downstream can dehydrate ethanol up to the required fuel grade (99.8%).

The non−fermentable products of the feedstock (known as whole stillage), consisting of suspended grain solids, dissolved materials (both solids and liquids) and water, are sent to a centrifuge where a wet cake (35% of solids by weight) and a thin stillage (8% of solids by weight) are obtained. Part of this last stream is recycled as the abovementioned backset, while the rest is sent to a multiple−effect evaporator. The evaporation units concentrate the stream up to a final solid content of 35% by weight (syrup). The syrup and the wet cake are mixed together and dried up to produce the DDGS, with a moisture content of about 10%, suitable for animal feeding.

1.2.2 Second generation bioethanol production processes

Biofuels produced by non−alimentary competitive feedstock are generally referred to as "second generation biofuels": those fuels are generally based on lignocellulosic raw materials. These raw materials can be wastes from agricultural and industrial processes or can be obtained from "energy crops" grown for that purpose. Actually, energy crops are in indirect competition with alimentary feedstock, since they can occupy a surface which could be used for alimentary crops. Nevertheless, biomasses have been selected so that energy crops can be grown on marginal lands, that are not apt to alimentary crops, thus minimizing also indirect competition between the two types of crops. This can also help to increase the value of marginal lands that otherwise would be abandoned or left in degradation. The most frequent energy crops for bioethanol production are miscanthus (Miscanthus giganteus), common cane

(Arundo donax), eucalyptus (Eucalyptus globulus) and poplar (Liriodendron tulipifera). On the other hand, the use of agricultural residues presents the risk of subtracting the land of their minerals and other factors that allow the successive crops to grow. The problem has been raised for corn stover, which is currently left in the field after the harvest, and whose removal has to be reintegrated by additional fertilizers. Furthermore, corn stover have an important role in limiting soil erosion, therefore it cannot be completely removed from a corn field.
All technologies using lignocellulosic materials are based on the same type of process, which is usually referred to as *LignoCellulosic Ethanol Process* (LCEP). This process can be found in multiple variants, but the most used one is the Diluted Acid Prehydrolysis process, whose block diagram is reported in figure 1.3.

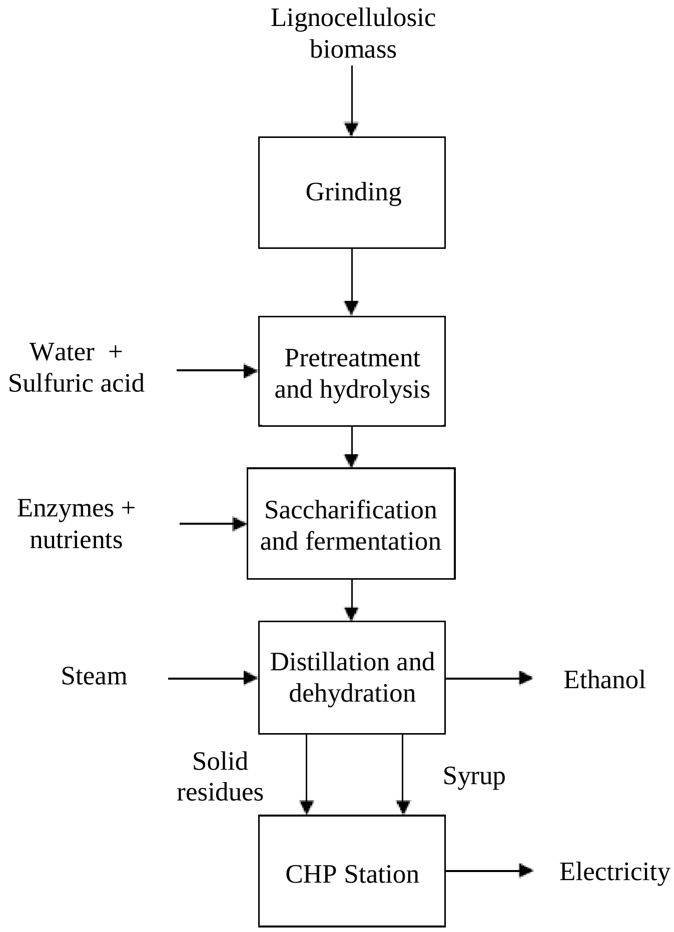

Figure 1. 3. *Scheme of the Diluted Acid Prehydrolysis process for ethanol and electricity production from lignocellulosic biomass.*

This process allows the enzymes to produce ethanol from the monomeric sugars obtained from the scission of the long chains of cellulose and hemicellulose that, together with lignin, make up the raw material structure.

Pretreatment, also called prehydrolysis, consists on treating biomass with a diluted sulfuric acid solution (1.1%) at high temperature (190 °C) for a short time (not more than 10 minutes): this transforms hemicellulose in soluble sugars; after that enzymatic hydrolysis (that is saccharification) is carried out. Fermentation occurs simultaneously with saccharification in most advanced processes. The final syrup contains about 6 % (w/w) of ethanol, and therefore it has to be purified and rectified before dehydration to obtain fuel−grade ethanol. Solid residues (mostly lignin) are burnt in a Combined Heat and Power (CHP) station that allows the whole plant not only to be self−sufficient of heat and electricity, but also to produce excess electricity. The technologies using this process have been included in the supply chain design simulation.

1.3 Bioethanol supply chain modeling

1.3.1 MILP programming and mathematical formulation

The problem addressed in this paper deals with the strategic design and planning of a general biofuel supply chain over a 15−years horizon. The optimization problem aims at the maximization of the NPV (Net Present Value, an index that resumes the profitability of an investment).

The structure of the biofuel SC taken as reference in this work is illustrated in figure 1.4.

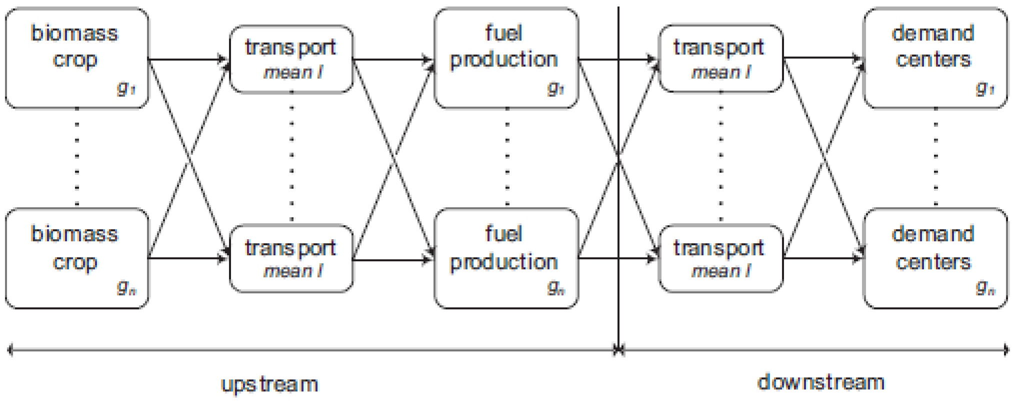

Figure 1. 4. *Biofuels network supply chain (from Giarola et al., 2011).*

It can be divided into two main substructures: the former concerns with the upstream fuel production and involves biomass cultivation, biomass delivery, and fuel production sites; the latter is related to the downstream product distribution to the demand centers.

Thus, strategic decisions in designing a biofuel production network deal with the geographical location of biomass cultivation sites, logistic definition of transport system and supply chain node location. On the other hand, planning decisions regard the capacity assignment of production facilities and the demand satisfaction along the time steps composing the time horizon. Accordingly, the optimization problem discussed here can be stated as follows. Given the following inputs:

(i) geographical distribution of demand centers;
(ii) fuel demand over the entire time horizon;
(iii) biofuel market characteristics in terms of prices distribution, as predicted by the price forecast models in chapter 2 and applied to supply chain model according to chapter 3;
(iv) biomass geographical availability;
(v) biofuel production facilities capital and operating costs;
(vi) biofuel demand per terminals, as defined by the different demand scenarios presented in chapter 3 and 4;
(vii) transport logistics (modes, capacities, distances, availability, and costs);

the objective is to determine the optimal system configuration in terms of SC profitability. Therefore, the key variables to be optimized over the planning time horizon are:

(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;
(vi) supply chain economic performance.

Fuel ethanol demand is set to vary along the 15−years time horizon, starting from 2012 to 2026. In accordance to the EU Directive, the biofuel quota was set equal to 5.75% (on energetic basis) in 2010 and from 2010 to 2019 minimum increments of fuel ethanol percentages are expected in order to achieve the EU target of 10%. In this work only gasoline blending has been considered, supposing that gasoline and diesel separately should reach the EU target, even if this is not compulsory: in fact, the 2010 biofuels target was almost reached thanks to the Italian biodiesel production, while the bioethanol one was negligible (USDA Foreign Agricultural Service, 2011). There, the increasing trend in the substitution quota was extended until 2026 in order to anticipate further regulations and delays in achieving the targets: the 10% quota was delayed by three years (since bioethanol part in 2010 was almost nil while the Directive expected biofuels to be at 5.75%) and 11.3% by energy is reached in 2026.

The overall time horizon has been divided into periods of three years, in order to reduce the computational burden (accordingly, each blending percentage is an average value over the time period).

The problem has been formulated as a Mixed Integer Linear Programming (MILP) modeling framework in order to capture the behavior of the entire supply chain and a spatially explicit approach has been adopted so as to consider the strict dependence on geographical features

characterizing biofuel systems. The mathematical formulation is based on the modeling approaches adopted in the strategic design of a multi−echelon supply chain encompassing features to address the siting of spatially explicit facilities (Almansoori and Shah, 2006) and capacity planning of strategic fuel systems (Hugo and Pistikopoulos, 2005).
The objective function to minimize is expressed in equation 1.2:

$$Obj = -NPV \quad , \tag{1. 2}$$

where Obj is the objective function [€], while *NPV* clearly indicates the Net Present Value, defined as the difference between the actualized cash flows and the investment capital:

$$NPV = \sum_t \left(CF_t \cdot \varepsilon_{CF,t} - TCI_t \cdot \varepsilon_{TCI,t}\right) \quad , \tag{1. 3}$$

where CF_t [€/time period] represents the cash flow, and TCI_t [€] stands for all the capital investments occurring at period *t*. Both terms are applied to the corresponding period−based discount factors, $\varepsilon_{CF,t}$ and $\varepsilon_{TCI,t}$ (Douglas, 1988), which are expressed the following equations:

$$\varepsilon_{CF,t} = \frac{1}{(1+\zeta)^{3(t-1)}}, \quad \forall t \tag{1. 4}$$

$$\varepsilon_{TCI,t} = \frac{3+3\zeta+\zeta^2}{3(1+\zeta)^{2t}}, \quad \forall t \tag{1. 5}$$

where ζ is the future interest rate. Here ζ has been assumed to be constant (Tsang, Samsatli and Shah, 2007) and equal to 10% as resulting from the application of the CAPM (Capital Asset Pricing Model) rule (Sharp, 1964).
The term CF_t of Eq. 1.3 is given by summing up the profit before taxes PBT_t [€/time period] and the depreciation charge D_t [€/time period] as well as deducting the tax amount TAX_t [€/time period]:

$$CF_t = PBT_t - TAX_t + D_t \quad , \qquad \forall t \tag{1. 6}$$

PBT_t is defined as the business incomes (Inc_t [€ /time period]) minus the overall operating costs, both fixed ($FixC_t$ [€ /time period]) and variable ($VarC_t$ [€ /time period]) ones, and minus the depreciation charge for each time period *t*:

$$PBT_t = Inc_t - VarC_t - FixC_t - D_t \quad , \qquad \forall t \tag{1. 7}$$

TAX_t is defined as the total tax amount. A taxation charge has to be applied only when a positive annual gross profit is obtained, otherwise it must be avoided; moreover, TAX_t, being a function of PBT_t, would make equation 1.6 a non−linear relation. Hence, the problem is overcome through the formulation of TAX_t by the two following equations:

$$TAX_t \geq Tr \cdot PBT_t \quad , \quad \forall t \tag{1. 8}$$

$$TAX_t \geq 0 \quad , \quad \forall t \tag{1. 9}$$

where Tr is the taxation rate, set equal to 36%, which represents a conservative approximation with respect to the current Italian taxation.

The business incomes for each time period t (Inc_t as referred to as in equation 1.7) come from the sum of the total revenues earned through the sale of product j (i.e. ethanol, DDGS or electricity) obtained from a conversion facility of technology k at time period t:

$$PBT_t = \sum_{k,g,j} P^{TOT}_{j,k,g,t} \cdot MP_{j,t} \quad , \quad \forall t \tag{1. 10}$$

where $P^{TOT}_{j,k,g,t}$ is the total production rate of product j obtained from a conversion technology k located in region g at time period t, while $MP_{j,t}$ is the market price of the good at that time period.

Variable costs ($VarC_t$ in eq. 1.7) account for biomass purchase costs (BPC_t [€/time period]), biomass transport costs (TCb_t [€/time period]), fuel distribution costs (TCf_t [€/time period]) and ethanol production costs (EPC_t [€/time period]) as they appear in the following equation:

$$VarC_t = BPC_t + TCb_t + TCf_t + EPC_t \quad , \quad \forall t \tag{1. 11}$$

BPC_t is evaluated by multiplying the total biomass i rate produced in region g at time period t, $Pb_{i,g,t}$ [t/time period], by the corresponding unit production costs, $UPC_{i,g,t}$ [€ /t], as it follows:

$$BPC_t = \sum_{i,g} Pb_{i,g,t} \cdot UPC_{i,g,t} + Still^{TOT}_t \cdot UPCS \quad , \quad \forall t \tag{1. 12}$$

where stillage total demand ($Still^{TOT}_t$) and price ($UPCS$) is taken into account. Stillage demand is linked to ethanol production rate through a conversion factor, which is zero for non stillage−requiring technologies. Stillage price has been considered to be constant through the time periods because of the wide availability of this raw material. Furthermore it was supposed that no stillage transportation was needed.

EPC_t is defined as the sum of two main contributions (Douglas, 1988), a linear function of the total production rate of ethanol, $P^{TOT}_{ethanol,k,g,t}$, and a fixed quota depending on the production technology adopted. That is made explicit by the following expression:

$$EPC_t = \sum_k \left(c_{k,slope} \cdot \sum_g P^{TOT}_{j,k,g,t} + c_{k,intercept} \cdot \sum_g Y_{k,g,t} \right) , \quad \forall t \tag{1. 13}$$

where $c_{k,slope}$ [€ /t] and $c_{k,intercept}$ [€ /time period] are the linear coefficients specific for each technology k and $Y_{k,g,t}$ is the binary variable accounting for whether a facility is operating with the conversion technology k in region g at time period t (a value of 1 is assigned when a plant is established, 0 otherwise).

With regard to transports, both the biomass delivery to conversion plants and the fuel distribution to blending terminals are treated as an additional service provided by existing actors already operating within the industrial/transport infrastructure. As a consequence, TCb_t and TCf_t are evaluated in the following equations:

$$TCb_t = \sum_{i,l} UTCb_l \cdot \left(\sum_{g,g'} Qb_{i,g,l,g',t} \cdot LD_{g,g'} \cdot \tau_{g,l,g'} \right) + UTCi_{i,g} , \quad \forall t \tag{1. 14}$$

$$TCf_t = \sum_{i,l} UTCf_l \cdot \left(\sum_{g,g'} Qf_{i,g,l,g',t} \cdot LD_{g,g'} \cdot \tau_{g,l,g'} \right) , \quad \forall t \tag{1. 15}$$

where $UTCb_l$ and $UTCf_l$ [€ /(t km)] are the unit transport cost for biomass i and ethanol via mode l, respectively; $Qb_{i,g,l,g',t}$ [t/time period] is the flow rate of biomass i, which needs to be transferred via mode l between two elements g and g' at time period t; $Qf_{g,l,g',t}$ [t/time period] is the flow rate of bioethanol to be delivered via mode l between two elements g and g' at time period t; $UTCi_{i,g}$ [€ /(t km)] is the unit transport cost for the transfer of biomass i within g; $LD_{g,g'}$ [km] is the local distance resulting from the measurement of the straight route between the centre of each network element g, and $\tau_{g,l,g'}$ is a tortuosity factor depending on the different transport mode l.

The term $FixC_t$, that appears in equation 1.7 accounts for the facility general expenses and is derived through the application of a fixed quota, φ set equal to 15% (Berk and De Marzo, 2008), to the global incomes.

A purposed−devised linearization model is used to achieve an accurate estimation of the capital expenditure (TCI_t), depreciation (D_t) and the total production capacity $P^{TOT}_{ethanol,k,g,t}$. This approach was suggested by Liu et al. (2007) and employed by Giarola et al. (2011) but some important modifications were added through this work and discussed in Appendix to more accurately take into account the costs for plant size changes. The linearization introduces two sets of discrete parameters, whose values define the capital investment ($CI_{p,k}$) to establish a production plant of nominal size p and technology k, and the corresponding facility scale (ER_p). The method is based on the linear combinations of the positive continuous variables $\lambda^{plan}_{p,k,g,t}$ and $\lambda_{p,k,g,t}$, which range between 0 and 1, and $\lambda^{grow}_{p,k,g,t}$ which ranges between −1 and 1; the abovementioned variables are interconnected and are bounded because of logical and physical constraints.

Ethanol production is evaluated as:

$$P^{TOT}_{ethanol,k,g,t} = \sum_{p} ER_p \cdot \lambda_{p,k,g,t} \quad , \qquad \forall t \tag{1. 16}$$

where $\lambda_{p,k,g,t}$ is a continuous recursive variable which has assumed a non–zero value since the moment an investment decision was taken and ER_p [t/time period] is the nominal production rate of ethanol for each plant size *p*. It is important to notice that the production rate of the other by–products is related to ethanol one through a conversion factor specific for each technology and for each by–product. The demand rate of each raw material is also expressed as a function of ethanol production rate: in this case the conversion factor is specific for each feedstock and for each technology.

The total capital expenditures result from the sum of the expenditures needed to establish the set of production facilities planned at time period *t* and the capital expenditures for plant enlargements as expressed by the following equation:

$$TCI_t = \sum_{p,k,g} CI_{p,k} \cdot \lambda^{plan}_{p,k,g,t} + Enl_{k,g,t} \quad , \qquad \forall t \tag{1. 17}$$

where $\lambda^{plan}_{p,k,g,t}$ is a continuous planning variable which is assigned a non–zero value only for the time period *t* in which the investment decision occurs, and $CI_{p,k}$ [€] is a parametric set needed to evaluate the capital investment related to the establishment of a production plant of size *p* and technology *k*; $Enl_{k,g,t}$ [€/time period] represents the costs for the enlargement of a plant of technology *k* located in region *g* at time *t*: this is defined in the following equation:

$$Enl_{k,g,t} = \sum_{p} \lambda^{grow}_{p,k,g,t} \cdot CI_{p,k} \quad , \qquad \forall t \tag{1. 18}$$

with the constraint that *Enl* must be greater or equal to 0 and using the variable $\lambda^{grow}_{p,k,g,t}$ to take into account changes in plant size.

D_t is determined through a linear approach and hence a fixed quota, *dk* is applied to depreciate the discounted total capital investment $TCI_{i,k,t}$, as stated below:

$$D_t = TCI_t \cdot dk \quad , \qquad \forall t \tag{1. 19}$$

The depreciation plan has been set according to the conventional procedure for the chemical industry (Douglas, 1988) by using *dk* equal to 0.175.

The linearization variables are bound through equation:

$$\lambda_{p,k,g,t} = \lambda_{p,k,g,t-1} + \lambda^{plan}_{p,k,g,t} + \lambda^{grow}_{p,k,g,t} \quad , \qquad \forall k,g,p,t \tag{1. 20}$$

Moreover, the two continuous variables, $\lambda_{p,k,g,t}$ and $\lambda^{plan}_{p,k,g,t}$, should be constrained by the actual planning decision expressed by:

$$Y_{k,g,t} = \sum_{p} \lambda_{p,k,g,t} \quad , \qquad \forall k,g,t \qquad (1.\ 21)$$

$$Y^{plan}_{k,g,t} = \sum_{p} \lambda^{plan}_{p,k,g,t} \quad , \qquad \forall k,g,t \qquad (1.\ 22)$$

where $Y^{plan}_{k,g,t}$ is the binary variable planning the establishment of a new production facility of technology k in region g at time t (a value of 1 means that the construction of a new production plant is allowed, otherwise 0 is assigned) and $Y_{k,g,t}$ is the recursive variable keeping memory of the plant establishment. This is ensured by equation:

$$Y_{k,g,t} = Y_{k,g,t-1} + Y^{plan}_{k,g,t} \quad , \qquad \forall k,g,t \qquad (1.\ 23)$$

Other logic constraints are related to the biomass demand per each region g, that cannot be more than the maximal biomass availability in that region, calculated on the basis of agronomic−related factors such as arable land and biomass yield in that region.
Furthermore, transport constraints were added in order to prevent the supply chain to allow infeasible routes, for instance transport by barges if a waterway is not available.

1.3.2 Previous achievements and motivations for this work

The bioethanol supply chain design in Northern Italy has been studied since 2008/2009 in the CAPE−Lab at the University of Padua and several papers have been published, focusing on both the economical and the environmental aspects of the supply chain (Zamboni, Bezzo and Shah, 2009). Some papers worked on the financial aspect of the bioethanol supply chain by using a stochastic approach in order to cope with the commodity prices uncertainty (Dal Mas et al., 2011), while others extended its usage to second−generation technologies (Giarola, Bezzo and Shah, 2011b). Further works are centered on the environmental aspect of the supply chain design, like taking into account water consumption (Bernardi, Giarola and Bezzo, 2012) or the greenhouse gases through the Emission Trading System (Penazzi, 2012).
Nevertheless, none of these studies simulated the supply chain forecasting the prices of commodities related to ethanol production during the time periods the supply chain will be operating. This is very important to correctly predict the supply chain economic performance and to have a realistic impact of the supply chain establishment on Italian taxpayers and fuel consumers, but also to evaluate the impact of different price evolution paths on the optimal supply chain. The principal goal of this work was to define models to predict commodity price evolution dynamics (chapter 2) and to extend the price forecasts to all other goods related to bioethanol production. Then, the optimal supply chain had to be tested under the

different evolution paths, to evaluate if it was a robust investment and how the economic performance depended on the commodity prices.

The study was also aimed to discuss the impact on the supply chain design of the recent European Commission proposal to amend the existing Directive which underlies to all the supply chain models used so far (chapter 4). In fact, the supply chain design depends on the underlying legislation that defines the biofuels demand and other specifications. Notably, this proposal significantly impacted the accountability technique for biofuels, therefore important changes in the supply chain design were expected. The changes in the demand for biofuels and in the limits for selected technologies implied a review of the supply chain model. Furthermore, it was an additional motivation for this work to assess the advantages and the drawbacks of the proposed modifications to the existing Directive.

Chapter 2

Commodity prices forecast

Since the profitability of a plant depends heavily on the prices of raw materials and sold products, it is a key aspect of the economic analysis of a process to estimate future prices of those goods. In the present chapter, different techniques to forecast corn and ethanol price will be introduced. First, historical data of corn and ethanol prices will be related to crude oil price through the Autoregressive Distributed Lag model (§2.1), then crude oil price itself will be forecasted for next 15 years, thanks to a stochastic approach (§2.2). The stochastic approach can also be applied to both corn and ethanol: the results will be illustrated in §2.3. Similar results to the ADL technique have been obtained through a model composed by a linear trend with oil−related function (§2.4). Finally, corn and ethanol prices will be estimated using a model that includes a periodical function built on a linear trend (§2.5).

2.1 Autoregressive Distributed Lag (ADL) model

2.1.1 Principles of the Autoregressive Distributed Lag model

A widely used model to express the linkage of a commodity price to a reference good price is the Autoregressive Distributed Lag Model (Stock and Watson, 2003). This technique permits to identify the functional time−dependence of the price of a commodity from its previous values and those of the reference component.

It seems appropriate to study the link between corn and fuel−grade ethanol with crude oil price. In fact, the price of a grain commodity can be affected by oil price in a number of ways. On the supply side, increases in the crude oil price push crop production costs up through fertilizers, fuel and transportation: therefore, they result in a price increase, as studied recently (Chen, Kuo and Chen, 2010). On the demand side, grain commodities are linked to the crude oil price through the competition of the demand for biofuels. In fact, biofuels can be regarded either as fossil fuel substitutes or as complementary goods (Marzoughi and Kennedy, 2012). In the first case, biofuels can substitute fossil ones in a percentage that is determined only by economic factors (eventually lower and upper boundaries can be set for technological issues), while in the second case their share in the final fuel is fixed even in the case where blending is not economically convenient. The law of supply and demand determines that in the former case, as fossil fuels prices increase, the demand for biofuels also increases, because it is increasingly convenient to blend them with fossil fuels. As a consequence, the prices of biofuels (and their relative raw materials, which are mostly grain commodities at Italian latitudes) increase. The situation is different if biofuels are considered as complementary goods to fossil fuels. In that case, if the price of fossil fuels increases, their demand will decrease, according to supply and demand equilibrium. Therefore, biofuel demand will decrease too, since their share on final fuel is fixed: this would relieve the biofuels and the grain commodities of some price pressure, as evidenced by a recent study (Yano, Blandford and Surry, 2010).

In econometric terms a mixed autoregressive model with *p* delays of the dependent variable, *Y*, and *q* delays of the independent variable, *X*, is defined as an Autoregressive Distributed Lag Model and denoted as ADL(*p*,*q*). The method has been recently employed to estimate the profitability of a hydrodealkilation plant by forecasting the price of toluene and benzene in relation with crude oil (Fini, Oliosi and Manca, 2011).

In this case an ADL(*1*,*1*) approach has been chosen, as a consequence of the analysis of historical data of corn and ethanol that is presented in the next paragraph. so that corn price is expressed as it follows (and equivalently for ethanol).

2.1.2 Analysis of historical data of corn and ethanol

In order to apply the ADL model it is necessary to draw the relation between the price of a commodity and crude oil one. To be as homogeneous as possible, historical data for corn, ethanol and crude oil were obtained from the market where they are most linked, that is where bioethanol from corn is most used as gasoline substitute: United States.

Historical data from 2008 were used in order to buffer the lag time between the approval of the Energy Policy Act and the large−scale use of bioethanol as a fuel. Furthermore, year 2008 recorded very high prices volatility, so it was a good period to test the model. WTI−Oklahoma quotations were used for crude oil prices, while corn prices were Iowa means and ethanol prices were U.S.A. averages, as reported by American universities records (Hofstrand, 2012). The Pearson correlation coefficient was used to quantify the linear dependence (that is correlation) between the variables. It is evaluated as in equation (2.1):

$$\mathrm{corr}_{X,Y}=\frac{\mathrm{cov}(X,Y)}{\sigma_X \cdot \sigma_Y} \ , \qquad (2.\ 24)$$

where cov(*X*,*Y*) is the covariance of the variables X and Y, while σ_X and σ_Y are the standard deviations of each variable. The correlation coefficients between corn and oil prices and between ethanol and oil prices were investigated, showing that there is an appreciable relationship: in fact maximum corn−oil correlation was 0.69 when there was no lag time and the maximum ethanol−oil correlation was 0.76, in the same conditions. It has to be remembered that two variables are perfectly correlated if Pearson correlation coefficient is 1 while they are anticorrelated if its value is −1.

In figures 2.1 and 2.2 the quotations of corn and ethanol are compared with the crude oil one for the period between January 2008 and September 2012. The graphs report crude oil price according to American standard in dollars per oil barrel, while corn is also expressed in American units as dollars per corn bushel (which corresponds to 25.4 kg) and ethanol price is indicated in dollars per gallon (equivalent to 3.78 l). The graphs represent weekly average prices for all commodities, as elaborated from Hofstrand, 2012.

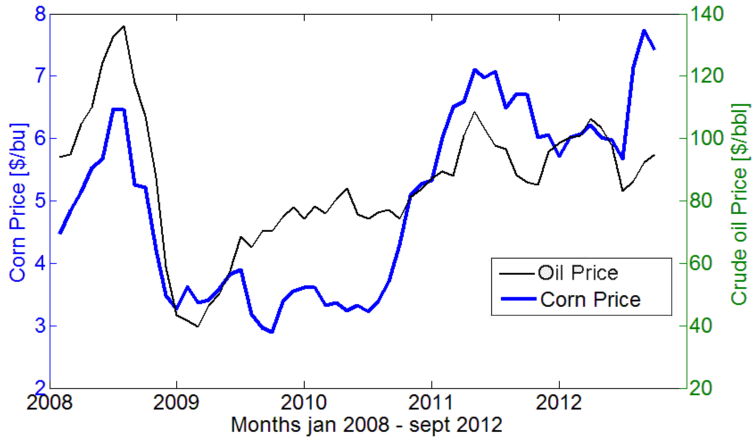

Figure 2. 1. *Dynamics of corn and crude oil prices since January 2008.*

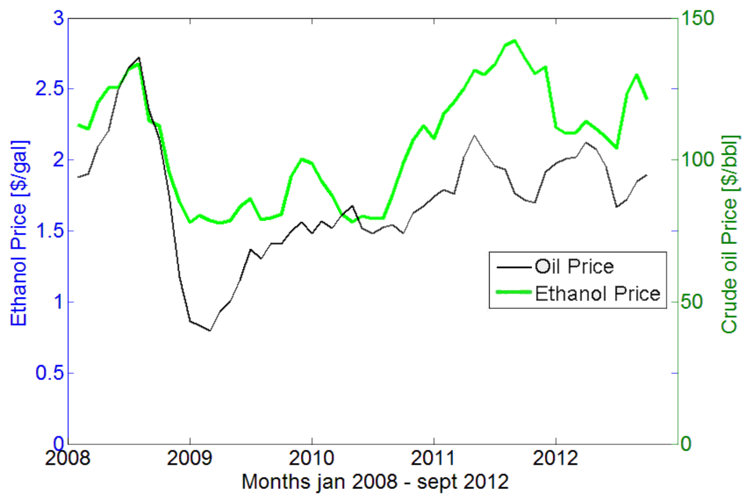

Figure 2. 2. *Dynamics of fuel−grade ethanol and crude oil prices since January 2008.*

Correlograms of corn and ethanol with oil will be shown in figures 2.3 and 2.4 for both corn and ethanol: they report the Pearson correlation coefficient of the commodity time series as a function of progressively increasing time shifts with crude oil.

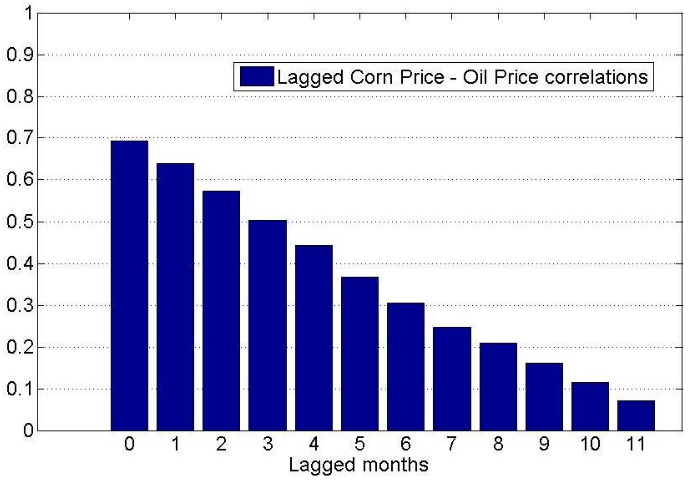

Figure 2. 3. *Correlogram of corn and crude oil prices.*

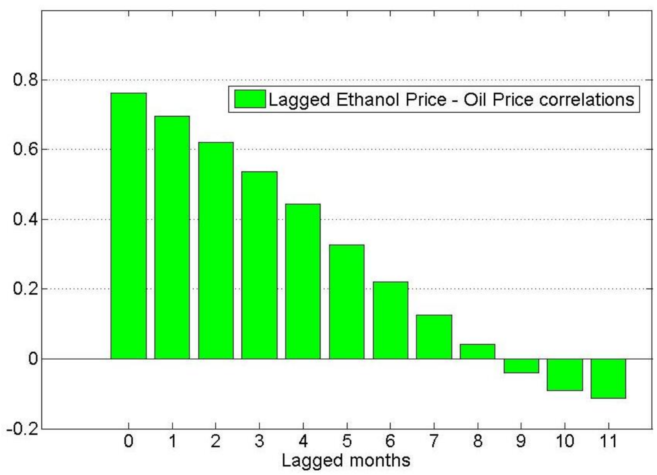

Figure 2. 4. *Correlogram of fuel-grade ethanol and oil prices.*

It can be seen on both diagrams that the commodity prices are mostly correlated to the crude oil price when the time lag is of 0 and 1 months, that is with prices of the same month and of the previous one. For this reason it has been chosen to include the dependence of both oil price values in the expression of the commodities prices. Furthermore, the previous value of the commodity price has been included in the expression of its future value, which permits to express the growth trend of the studied commodity.

Finally, the corn price function is expressed in equation 2.2:

$$CornPrice_t = A_C + B_C \cdot OilPrice_t + C_C \cdot OilPrice_{t-1} + D_C \cdot CornPrice_{t-1} \;, \tag{2. 25}$$

where *CornPrice* indicates the price of corn ($/bu) and *OilPrice* the quotation of oil ($/bbl). The parameters of the abovementioned equation were calculated with MATLAB ® (v. 2011b, the MathWorks Inc.) minimization tools, on the base of data from January 2008 until December 2011, and then validated by comparison with real 2012 data.

Since the optimal regression can be obtained through several sets of parameters, it has been chosen to set the same relative growth trend for both commodity prices (that is equivalent parameters D_C and D_E).

The obtained parameters for the corn price function are reported in the following table:

Table 2. 1. *Parameters of the corn price forecast function.*

Parameter	Value	Units
A_C	−0.1317	[$/bu]
B_C	0.0467	[bbl/bu]
C_C	−0.0448	[bbl/bu]
D_C	1.001	[−]

The model with the calculated parameters shows good fit with real data, in fact the coefficient of determination R^2 is equal to 0.72. Figure 2.5 compares the estimated prices with the real ones.

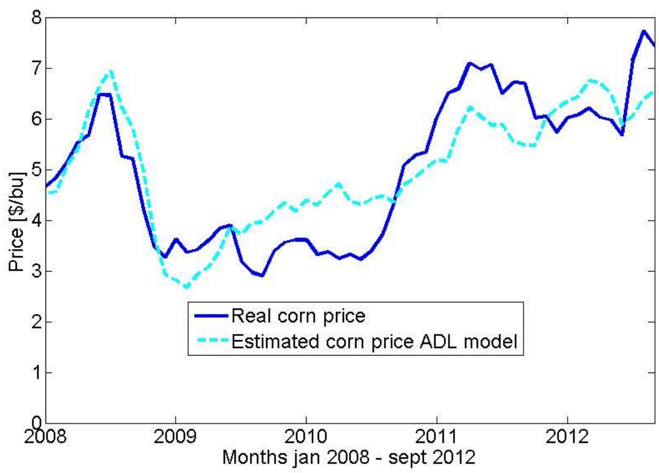

Figure 2. 5. *Comparison of real corn price with ADL-estimated corn price.*

The same study has been conducted on ethanol using data from the same time span.

The equation is in the same form (equation 2.3):

$$EthanolPrice_t = A_E + B_E \cdot OilPrice_t + C_E \cdot OilPrice_{t-1} + D_E \cdot EthanolPrice_{t-1} \ , \quad (2.26)$$

where *EthanolPrice* indicates the price of fuel−grade ethanol ($/gal). The values of the parameters of the function are reported in the following table:

Table 2. 2. *Parameters of the ethanol price forecast function.*

Parameter	Value	Units
A_E	0.0109	[$/gal]
B_E	0.0155	[bbl/gal]
C_E	−0.0156	[bbl/gal]
D_E	1.001	[−]

In this case the coefficient of determination is slightly worse (R^2 = 0.59), but figure 2.6 shows that the predictions are more than acceptable, since the forecast errors never exceed 50 c$/gal except in March 2010 and July 2011 when this error margin is reached..

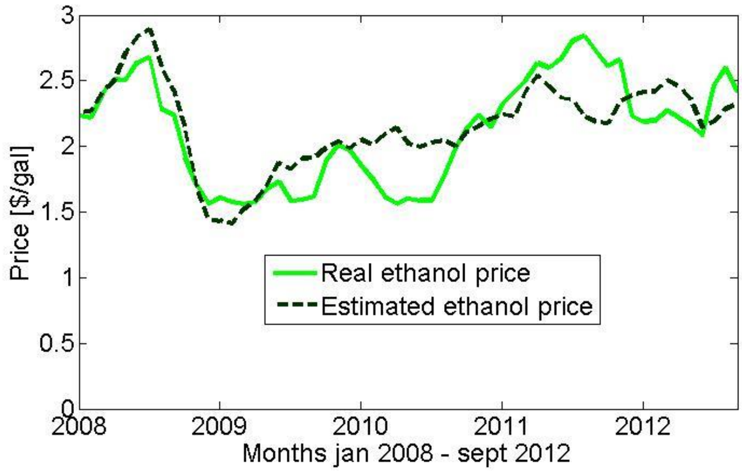

Figure 2. 6. *Comparison of real ethanol price with ADL-estimated ethanol price.*

2.2 Oil price forecast model

2.2.1 The technique

Once determined the relationships of corn and ethanol prices with oil price, it is necessary to forecast this latter, in order to use the ADL model for forecasting purposes.

The principle is the same as in the work by Fini et al. (2011): a rule in the evolution of oil price variations has to be identified in order to replicate it in the future. First, the oil price

shocks (that are relative variations regard to the previous time unit) are studied, in order to understand if they follow a known distribution, then the parameters that determine the function were retrieved and finally crude oil price forecasts were defined.
Notably, it has been shown that oil price shocks are independent from the previous ones and they are distributed according to a Normal distribution, so oil price shocks have been simulated as a Markovian process. In fact, a Markovian process is a stochastic discrete process in which the transition probability to a new state of the system is only determined by the previous state and not by the way it has been reached (Häggström, 2002).

2.2.2 Analysis of historical data of crude oil price

An analysis of the relative change of historical prices of crude oil related to the previous week (the so called "shock", as reported in equation 2.4) allows to appreciate the price volatility of crude oil.

$$ShockOil_t = \frac{CrudeOilPrice_t - CrudeOilPrice_{t-1}}{CrudeOilPrice_{t-1}} \quad , \qquad (2.27)$$

where $ShockOil_t$ is the week t relative variation of crude oil price. Weekly variations have been calculated from the WTI Oklahoma crude quotations. It is worth noticing that they are limited to a ±15% level, as it can be seen by figure 2.7.

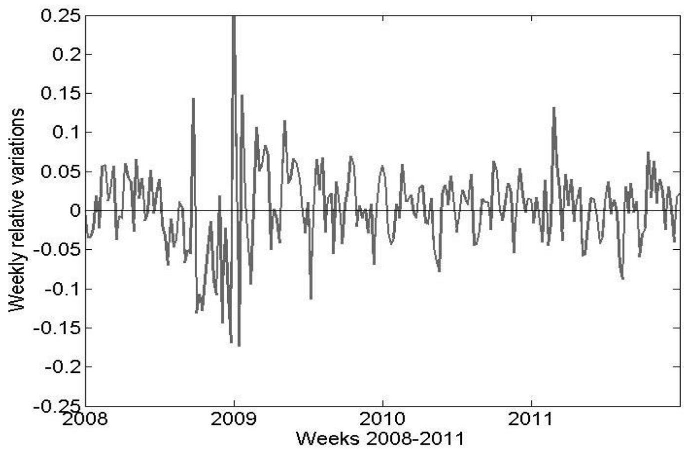

Figure 2. 7. *Weekly oil price relative variations ("shocks") between 2008 and 2011.*

Cumulative price variations have been stacked in order to estimate the profile of the distribution and the result is shown in figure 2.8. Good fit has been obtained with a normal distribution with same mean and standard deviation of the analyzed data.

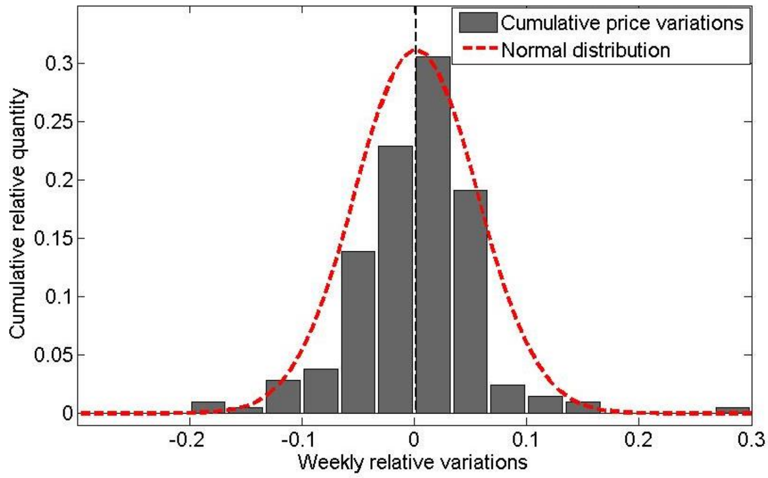

Figure 2. 8. *Cumulative "price shocks" relative quantity and comparison with a Normal distribution with same mean and standard deviation of the "shocks".*

The parameters of the curve are reported in table 2.3.

Table 2. 3. *Parameters of the distributions of crude oil relative variations.*

Parameter	**Value**
Mean (μ)	0.0015
Standard deviation (σ)	0.0541

The fact that the distribution has mean different than 0 suggests that more increasing shocks were present in the period 2008−2011 than decreasing ones. It has been then demonstrated that oil price variations have no dependence on previous variations, since lagged Pearson correlation never goes beyond 0.25, thus confirming that the process is a Markovian one. Consequently, it is appropriate to use a stochastic technique, tuned on previously determined data, to forecast oil price. The proposed relation is illustrated in equation 2.5:

$$CrudeOilPrice_t=CrudeOilPrice_{t-1}\cdot(1+\mu+\sigma\cdot\zeta)\ , \qquad (2.\ 28)$$

where ζ is a function whose output is a random number with mean 0 and standard deviation 1. The proposed formula allows to calculate weekly oil price. Monthly averages were obtained for usage in the ADL model.

2.2.3 Crude oil price evolution scenarios

Since the provided formulation is stochastic, the proposed formula has been used to compute 2000 simulations, in order to have a consistent number of "oil price scenarios" for the

following years. Then, the different values of oil price provided by the simulations have been grouped in regions whose probability to occur is the same.
Cumulative probability areas have then been plotted (figure 2.9), in order to have a "fan chart", also known as "river of blood" (Stock and Watson, 2003) that indicates the probability of a variable to take a certain value in the future.
Predictions have been compared with real 2012 data, showing very good accordance with the most probable regions of the graph (the "hottest" ones), thus confirming the quality of the simulation. The comparison is shown in the figure 2.10.

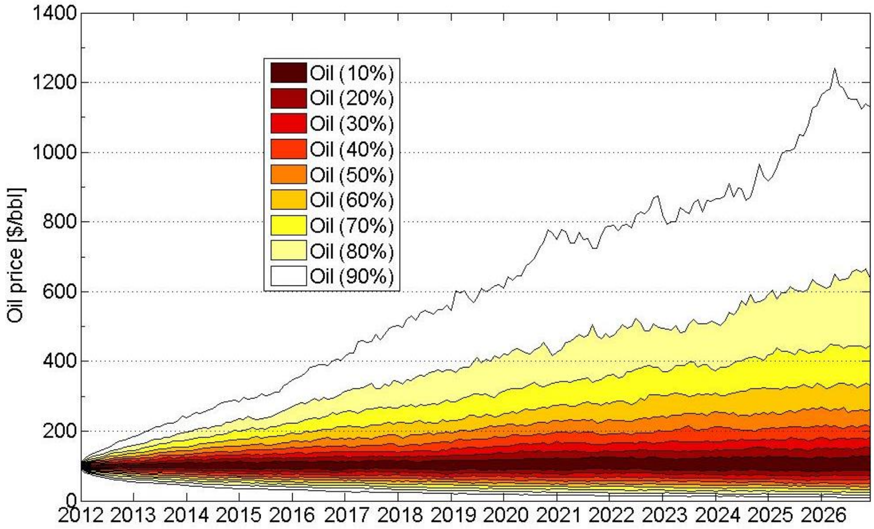

Figure 2. 9. *Cumulate probability regions of future crude oil price.*

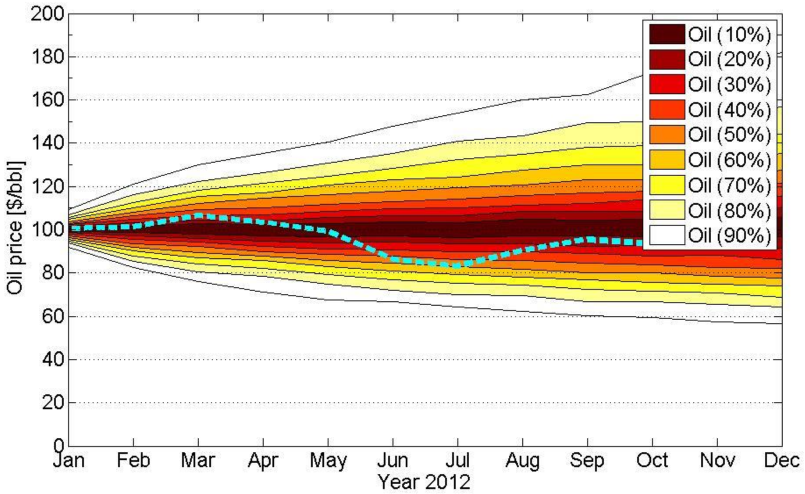

Figure 2. 10. *Comparison between crude oil price probability regions and real 2012 crude oil price (dashed).*

2.2.4 Application to the ADL model

The forecast of crude oil price in the period of interest allows to apply the identified relation of the ADL model between commodity price and oil price (§2.1.1) to obtain future commodity prices.

Since crude oil price follows a stochastic distribution, it is not possible to identify a unique "crude oil function" to insert in the commodity price relation. It has been decided to define three "notable" crude oil profiles and to use them for the calculation of commodity price.

i) The first, also called "best case", represent a scenario of extremely low oil prices and it accounts for every time period the simulated oil price that stays below of 90% of the simulated prices (that is that exceeds 10% of the simulated prices, which is equivalent): it represents the lower boundary of the previous "fan charts";

ii) The second, also called "worst case", represent a scenario of extremely high oil prices and it accounts for every time period the simulated oil price that exceeds 90% of the simulated prices: it represents the upper boundary of the previous "fan charts";

iii) The third, also called "intermediate case", represent a scenario of intermediate oil prices and it accounts for every time period the simulated oil price that exceeds 50% of the simulated prices: it represents the average prices of the most probable region of the previous "fan charts".

It was already shown that real oil prices show good accordance with the intermediate region (figure 2.10), but also real corn and ethanol prices are close to the intermediate forecasts (as it can be seen in figures 2.11 for corn and 2.12 for ethanol). Therefore, the intermediate case is considered as the reference scenario for future forecasts.

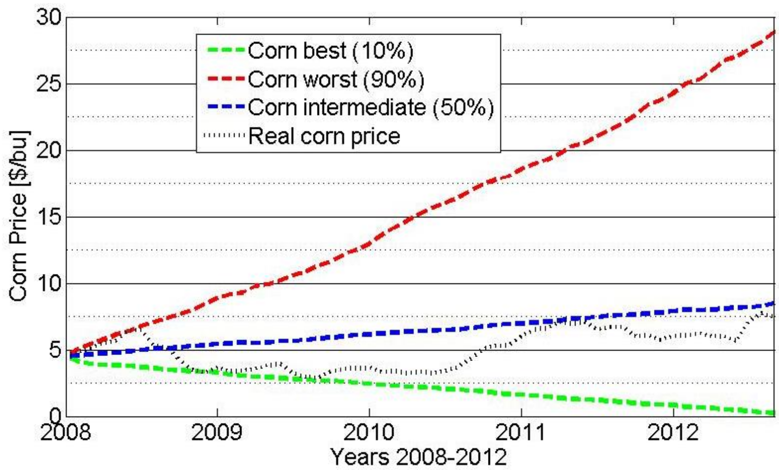

Figure 2. 11. *Comparison of real corn price (dotted black) with three notable evolution scenarios.*

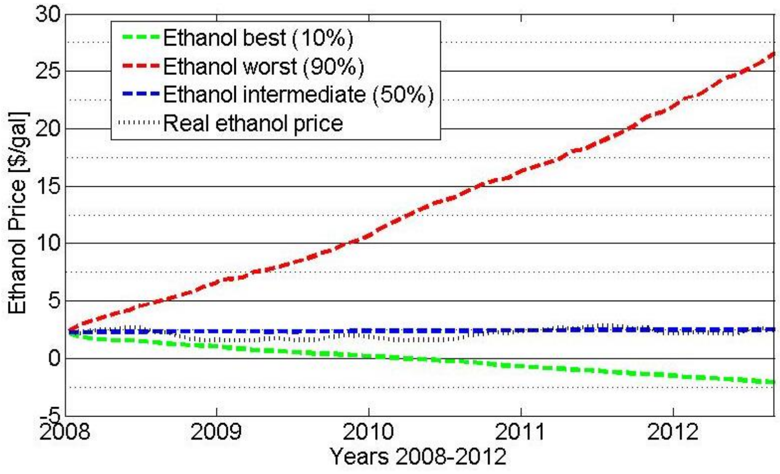

Figure 2. 12. *Comparison of real fuel-grade ethanol price (dotted black) with three notable evolution scenarios.*

Furthermore, the intermediate scenario represents properly the most probable region, and so it dampens the oscillations typical to commodities prices. As a consequence, the forecasted prices for corn and ethanol as required by the supply chain model have been calculated through equations 2.2 and 2.3 under an intermediate scenario. The defined model has the advantage that it can be implemented on different crude oil price profiles, thus allowing to study the consequences on commodities themselves of a specific path. The quotations obtained with the intermediate scenario are reported in table 2.4.

Table 2. 4. *Forecasted corn and ethanol prices using the ADL(1,1) model under intermediate scenario.*

Forecasted good	**2012−2014**	**2015−2017**	**2018−2020**	**2021−2023**	**2024−2026**
Corn price [$/bu]	8.78	11.35	14.24	17.04	20.09
Ethanol price [$/gal]	2.43	2.60	2.77	2.85	3.01

The correspondent prices in the European units (see also §3.1) are from 256 €/t to 587 €/t for corn and from 0.67 €/kg to 0.83 €/kg for ethanol.

2.3 Fully stochastic model

2.3.1 Principles of the model

The dynamics of the prices of each commodity can be studied as done for oil in § 2.2.1 and forecasts can be drawn in an equivalent manner, once proven that their behavior can be described as a Markovian process. For this reason the prices of each commodity has been studied by analyzing the weekly relative variations from 2008 and by defining their underlying distribution, if any existed. Eventually it has been verified whether the weekly variations have "memory" of the past by evaluating their lagged autocorrelation. Once the weekly variations were proven to follow a Markovian process, their distribution is then used to foresee price evolution scenarios in a stochastic manner by obtaining a fan chart as for oil.

With concern to corn price relative variations, it can be seen in figure 2.13 that they are limited within a narrow range (±10% level except for a couple of exceptions) and their cumulate distribution fits well with a normal distribution (figure 2.14).

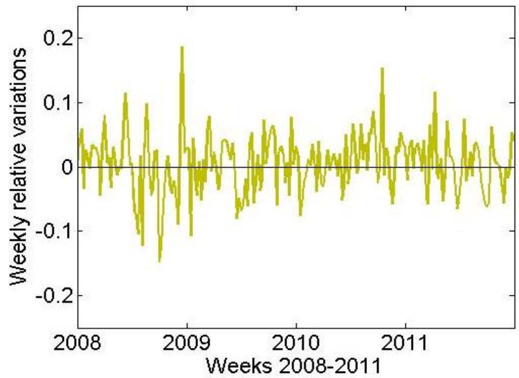

Figure 2. 13. *Weekly corn price relative variations in the period 2008-2011.*

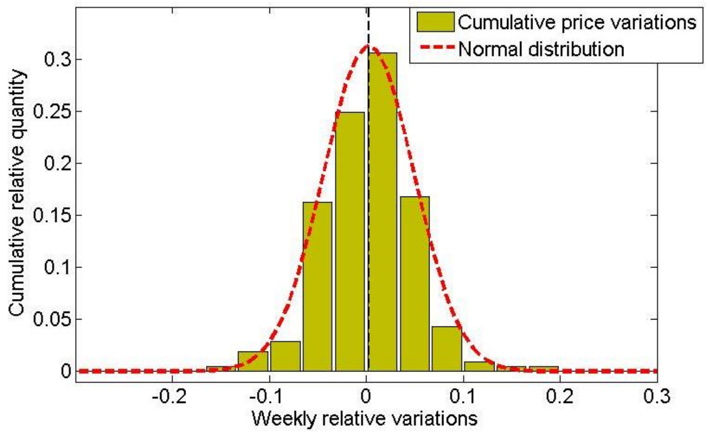

Figure 2. 14. *Cumulative relative quantity of weekly relative variations compared with a Normal distribution with same mean and standard variation of the weekly variations.*

The mean and the standard deviation of the distribution are obtained from the weekly shocks data and they are reported in table 2.5. It can be noticed that also in this case the mean of the distribution is greater than zero, thus indicating a tendency towards price increase.

Table 2. 5. *Parameters of the distributions of corn relative variations.*

Parameter	Value
Mean (μ_c)	0.0027
Standard deviation (σ_c)	0.0467

In order to study if variations are independent on the previous ones, correlations between January 2011− December 2011 variations and lagged variations have been calculated, showing that the correlation is minimal (figure 2.15).

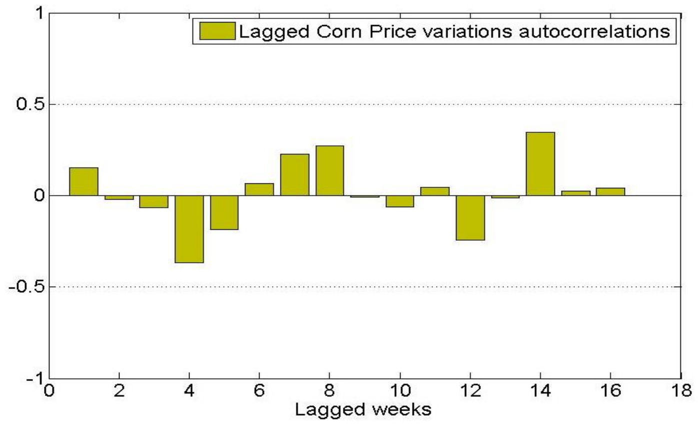

Figure 2. 15. *Autocorrelogram of corn price relative variations.*

Therefore the hypothesis to assume the process as a Markovian one is confirmed. Corn prices forecasts have consequently been drawn from the reconstructed Markovian process, as defined by equation 2.6:

$$CornPrice_t = CornPrice_{t-1} \cdot (1 + \mu_C + \sigma_C \cdot \zeta) \quad , \tag{2. 29}$$

where again ζ is a function whose output is a random number with mean 0 and standard deviation 1.

Since the provided formulation is stochastic, the proposed formula has been used to compute 2000 simulations, in order to have a consistent number of “corn price paths” for the following years. Then, the different values of corn price provided by the simulations have been grouped in regions whose probability to occur is the same.

The same technique has been applied to ethanol price variations.

The variations have been observed to be randomly distributed in a Normal way, with the main difference with corn that the mean is significantly smaller, and that is qualitatively confirmed by the fact that ethanol showed a slower increasing trend than corn in last years. For sake of precision, the variations' mean corresponds to 0.17‰ of the average ethanol price in the analyzed period, while it is 0.54‰ of the average corn price in the same time span.

Table 2. 6. *Parameters of the Normal distribution of ethanol relative weekly variations.*

Parameter	Value
Mean (μ_E)	0.00037
Standard deviation (σ_E)	0.0369

Furthermore, it was proven that the variations are not autocorrelated the one with the others, as it can be seen in figure 2.15.

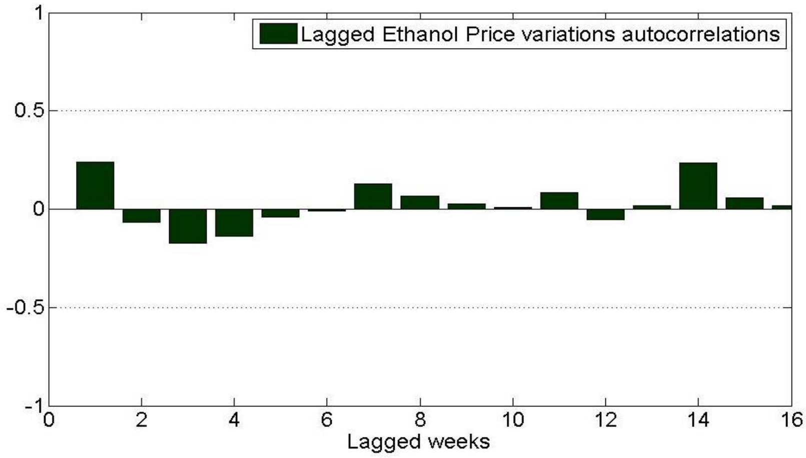

Figure 2. 16. *Autocorrelogram of ethanol relative variations.*

As for corn, ethanol price dynamics is described as a Markovian process (equation 2.7)

$$EthanolPrice_t = EthanolPrice_{t-1} \cdot (1 + \mu_E + \sigma_E \cdot \zeta) \quad , \tag{2. 30}$$

In the following paragraph the results of the simulations according to this distribution will be presented.

2.3.2 Results

The plots in figures 2.17 and 2.19 show the "River of blood" for corn and ethanol prices. It can be noticed that in both cases real 2008−2012 data fall within the 90% cumulate probability region and they show good fit with the most probable area of the graph (in both case the darkest one). The comparison is detailed for corn in figure 2.18.

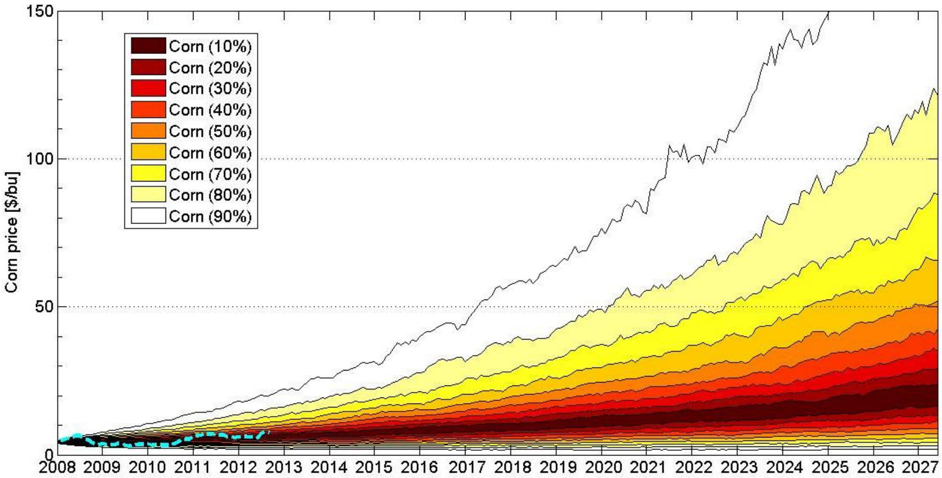

Figure 2. 17. *Cumulate probability regions of future corn price by year. In dashed blue real corn prices.*

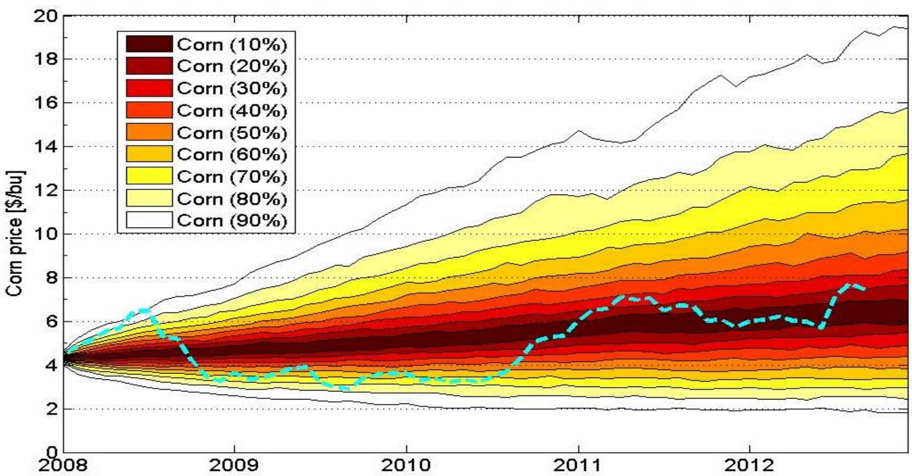

Figure 2. 18. *Confrontation between corn price probability regions and real corn price (dashed).*

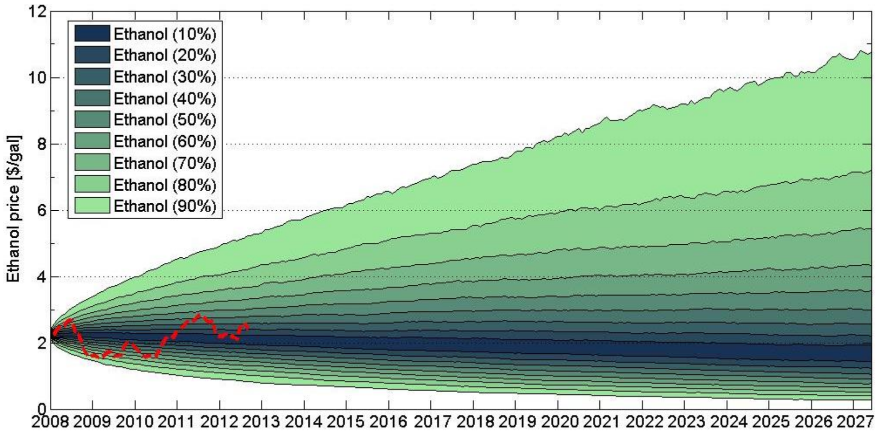

Figure 2. 19. *Cumulate probability regions of future ethanol price by year. In dashed red, real ethanol prices.*

Furthermore, it is worth noticing that corn prices are expected to grow significantly over next years, as it can be seen by the trend of the most probable region, while ethanol prices have grown so little in the last period that their average quotation is expected to decrease in future. The reasons of this behavior will be discussed in the following paragraph.

If the most probable region is considered as the most reliable one for the future average quotations of the commodities, its average value can be chosen to predict the average price of both corn and ethanol in every moment. The period average prices of corn and ethanol according to the fully stochastic model are reported in table 2.7.

Table 2. 7. *Forecasted corn and ethanol prices using the fully stochastic model.*

Forecasted good	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Corn price [$/bu]	6.65	8.25	10. 50	13.09	16.30
Ethanol price [$/gal]	2.07	1.97	1.87	1.77	1.70

As the graphs also show, ethanol prices are expected to decrease (figure 2.19), thus reaching 0.47 €/kg from 0.57 €/kg, while corn prices are expected to grow (figure 2.17) that is they are expected to reach from more than 475 €/t in the last period, up from 194 €/t in the first one.

2.3.3 Comments on the ethanol trend

At first sight it appears meaningless the fact that ethanol most probable price is expected to decrease while the distribution of its relative variations has mean greater than 0, thus meaning that in the past increasing variations were more abundant than decreasing one.

Actually, the behavior of the stochastic process is caused by the properties of the underlying model and the fact that iso−probability regions are narrower under the average values than above is linked to the same issue.

In fact, if we suppose that at time *t* the commodity price is *x*, the probability that in *t+1* the price will be $^3/_4\, x$ is the same that in the same time period the price will be $^5/_4\, x$, because the Normal distribution has mean close to 0. If the price in *t+1* was $^3/_4\, x$, the probability that it would reach again the value of *x* in *t+2*, would in the order of 10^{-18}, while if it was $^5/_4\, x$ in *t+1,* the probability that in *t+2* it would be *x* again would be of 10^{-7}. That means that the price that is ¾ of the first one has 10^{-11} times the probability to reach again the reference value compared to the one that is $^5/_4$ of the reference value, and that is due to the fact that in the former case the random function has to take a value which is farther from the distribution mean than in the latter case ($^4/_3$ compared with $^4/_5$).

The analytical explanation of this behavior has to be researched through the use of the Ito integral calculus, which extends the concept of integration to stochastic process. Notably, according to Ito's calculus the mean of the stochastic processes generated by a distribution of mean μ, corresponds to an equation of mean $\mu - \sigma^2/2$, where σ is the standard deviation of the generator distribution. In this case the "generator" distribution is the one described by ethanol price variations.

The curve whose trend is equal to $\mu - \sigma^2/2$ has been plotted in dashed white against the "river of blood" for ethanol forecasts, showing perfect fit with the expected most probable region. The same can be shown for the other commodities.

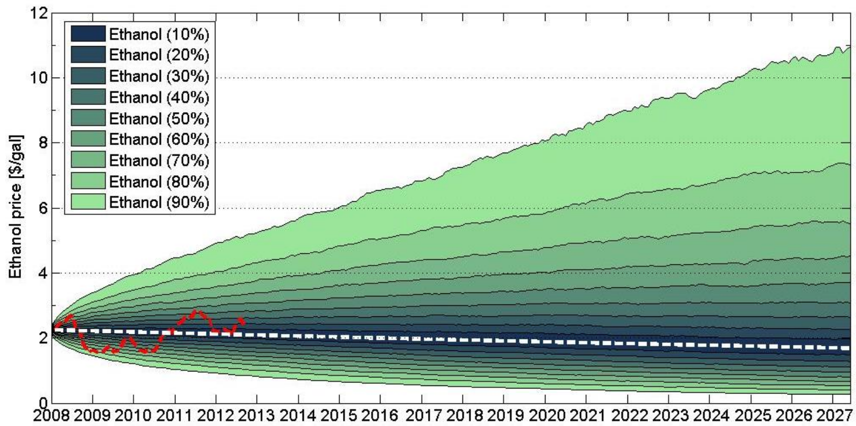

Figure 2. 20. *"River of blood" for ethanol price forecasts compared with real ethanol prices (dashed red) and Ito-calculated mean of the distribution (white).*

Therefore, the resulting decrease of the most probable region is caused by the high standard deviation and the low mean of the ethanol price shocks and its trend is due to an endogenous characteristic of the stochastic processes.

2.4 Linear model with oil−related fluctuations

2.4.1 Principles of the model

As it has been demonstrated before, the ADL model can be used as a basis for expressing the relation between commodity and oil price, but some modifications are desired, in order to take into account other effects than oil on commodities prices. The proposed approach to solve the problem is to decompose the commodity series into a linear trend and a component based only on oil price, which would account for all the fluctuations from the linear trend. Even if a trend component has been included in the ADL model, through the parameter that multiplies the commodity price in the previous time period, the modifications in this model allow the forecasted quotations to be "independent" of the previous value, that could have suffered from high fluctuations, and to take only into account the intrinsic trend of the commodity. In the case of corn that would take the form expressed by equation 2.8:

$$CornPrice_t=(q+\mathrm{m}\cdot t)\cdot(\mathrm{A}+\mathrm{B}\cdot CrudeOilPrice_t+\mathrm{C}\cdot CrudeOilPrice_{t-1}) \quad , \tag{2. 31}$$

where m and q are the parameters of the linear component, while A, B and C are the ones of the oil−related one. The parameters of the abovementioned equation were calculated with MATLAB ® minimization tools, based on data from January 2008 until December 2011 and validated with 2012 data, that is the model parameters have been calculated by fit with real data until 2011 and the fit has been evaluated by comparing the extrapolated prices with real 2012 data.
The obtained parameters are reported in table 2.8:

Table 2. 8. *Parameters of the corn price forecast function.*

Parameter	Value	Units
q	3.5250	[$/bu]
m	0.0502	[$/(bu*number of months since Jan 2008)]
A	0.1450	[−]
B	0.0098	[bbl/$]
C	0.0002	[bbl/$]

The model with the calculated parameters shows good fit with real data (as it can be seen from figure 2.21), in fact the coefficient of determination R^2 is equal to 0.71 but it does not provide many improvements compared with the ADL model, as it can be seen from figure 2.22.

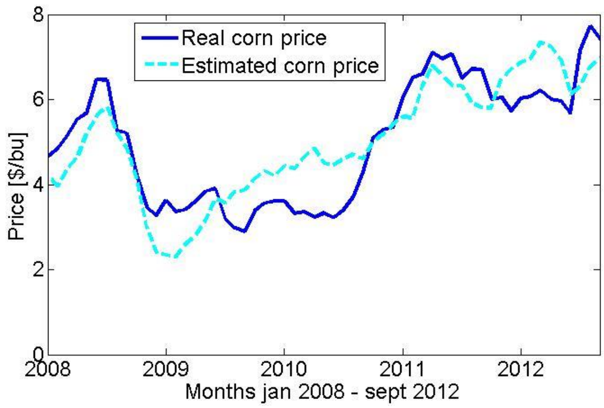

Figure 2. 21. *Comparison of real course of corn with the estimated one using the linear model with oil-related fluctuations*

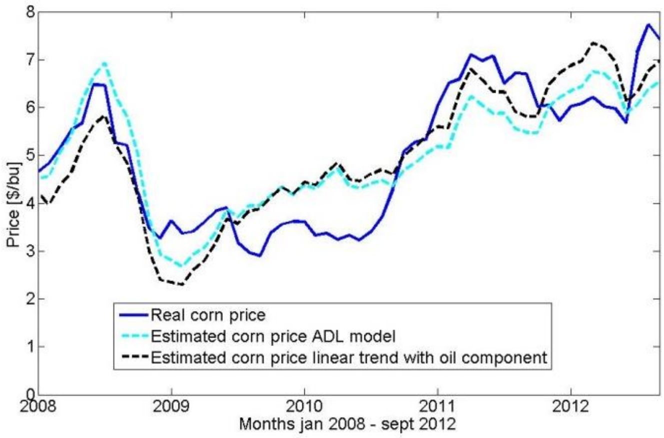

Figure 2. 22. *Comparison of forecasted corn price with the linear model with oil-related fluctuations (black) with the ADL model (cyan) and with real corn price (blue)*

The same study has been conducted on ethanol using data from the same time span. The equation was in the same form, that is

$$EthanolPrice_t=(q'+m'\cdot t)\cdot(A'+B'\cdot CrudeOilPrice_t+C'\cdot CrudeOilPrice_{t-1}) \quad (2.\ 32)$$

The values of the parameters of the function are reported in the table 2.9:

Table 2. 9. *Parameters of the ethanol price forecast function.*

Parameter	Value	Units
q’	1.8393	[$/gal]
m’	0.0094	[$/(gal* number of months since Jan 2008)]
A’	0.4024	[−]
B’	0.0071	[bbl/$]
C’	−0.0002	[bbl/$]

As with the ADL model, the forecasts for ethanol show lower coefficient of determination than for corn (in this case $R^2 = 0.65$), and again the quality of the ADL estimations does not dramatically increases. It can be seen from figure 2.2.3 that the predictions are nevertheless more than acceptable.

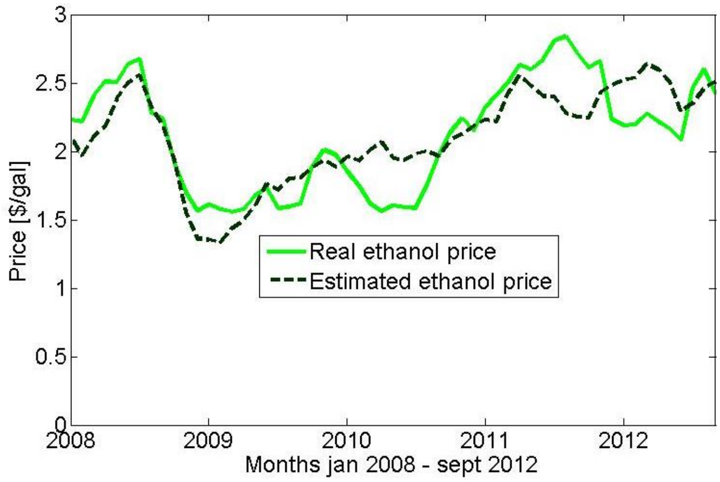

Figure 2. 23. *Comparison of real fuel-grade ethanol price with the one estimated with the linear model with oil-related fluctuations.*

2.4.2 Results

In order to use this model to forecast commodities prices in following years, it is necessary to have estimates of the oil price in the same periods.

The same approach as in §2.2 has been used, therefore it has been decided to define three “notable” crude oil profiles as a reference for the calculation of commodities prices. They are recalled here using the same notations as in § 2.2.4:

i) The first, also called “best case”, represent a scenario of extremely low oil prices and it accounts for every time period the simulated oil price that stays below of 90% of the simulated prices (that is that exceeds 10% of the simulated prices, which is equivalent): it represents the lower boundary of the previous “fan charts”;

ii) The second, also called “worst case”, represent a scenario of extremely high oil prices and it accounts for every time period the simulated oil price that exceeds 90% of the simulated prices: it represents the upper boundary of the previous “fan charts”;

iii) The third, also called “intermediate case”, represent a scenario of intermediate oil prices and it accounts for every time period the simulated oil price that exceeds 50% of the simulated prices: it represents the average prices of the most probable region of the previous “fan charts”.

Since real oil price shows better accordance with the intermediate region (§ 2.2.3) and also real corn and ethanol prices are closer to the intermediate forecasts (as it can be seen by following graphs), the intermediate case is considered as the reference scenario for future forecasts.

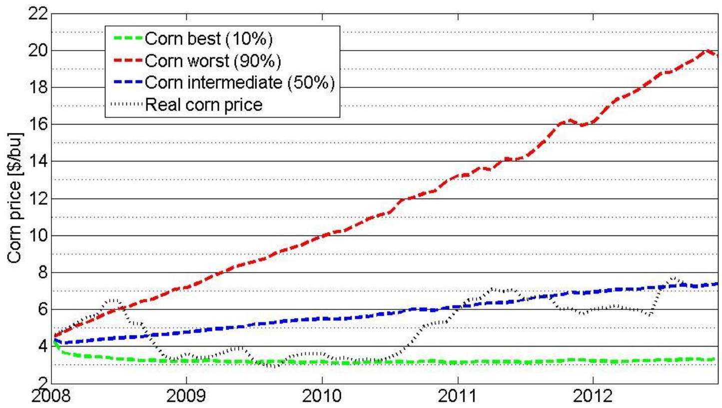

Figure 2. 25. *Comparison of real corn price (dotted black) with three notable evolution scenarios of the linear model with oil-related fluctuations.*

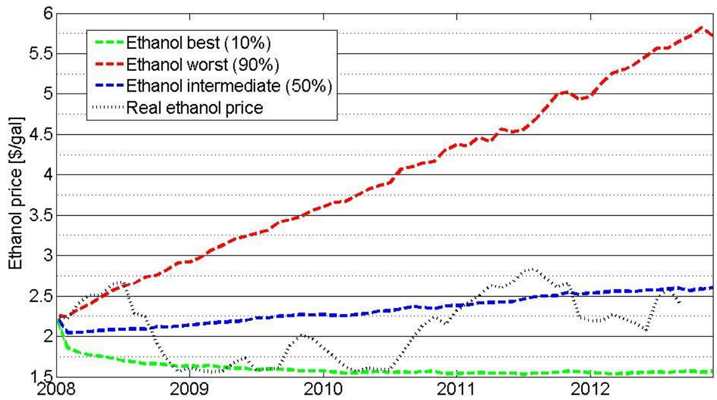

Figure 2. 24. *Comparison of real ethanol price (dotted black) with three notable evolution scenarios of the linear model with oil-related fluctuations.*

As a consequence, the forecasted prices for corn and ethanol in the future time periods have been calculated using the intermediate scenario forecasts.

Table 2. 10. *Forecasted corn and ethanol prices using the oil−related with trend component model.*

Forecasted good	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Corn price [$/bu]	7.74	9.79	12.20	14.17	16.61
Ethanol price [$/gal]	2.66	3.03	3.47	3.82	4.26

The forecasted values show higher prices than previous models for ethanol, rising from 0.73 €/kg to 1.17 €/kg, while corn grows from 226 €/t to 486 €/t.

2.5 Periodical with trend component model

2.5.1 The approach

Corn and ethanol prices showed in last years an increasing trend with many peaks and troughs, whose succession seems to have a certain periodicity, as it can be shown by the behavior of corn price in Italy in the last decade (figure 2.26) for which the corn quotations at the Borsa Granaria in Milan have been used (Associazione Granaria di Milano, 2012).
One of the most used techniques to evaluate the composite behavior of a time series is the Time Series Decomposition Method (Zarnowitz and Ozyildirim, 2006), that evaluates a time series as the product of a trend function with a periodical one and the residuals are considered as a random contribution.

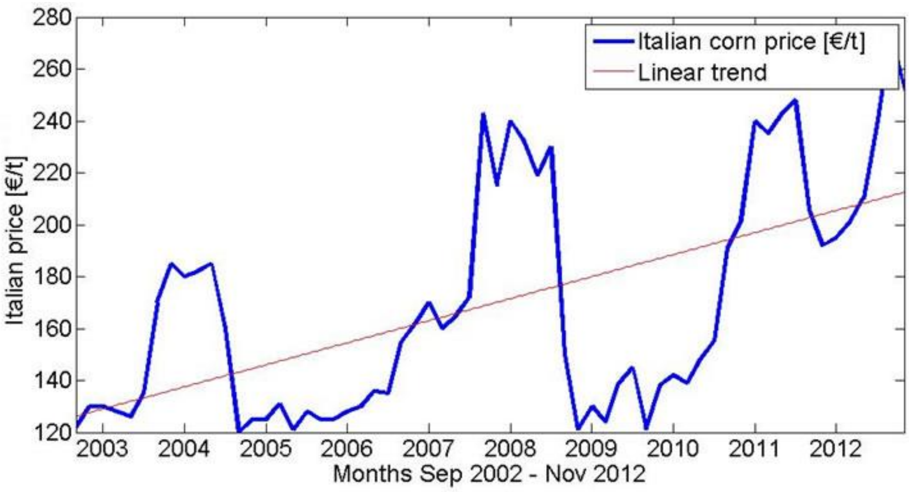

Figure 2. 26. *Italian corn price in the last decade compared with a linear trend.*

Therefore, it was decided to verify if commodities prices follow this kind of rule and to use the obtained model to estimate the future behavior of commodities prices. In the case of corn the model would be in the form of equation 2.10:

$$CornPrice_t=(q_{CC}+m_{CC}\cdot t)\cdot(A_{CC}+B_{CC}\cdot\sin\left(\frac{2\pi\cdot t}{T_{CC}}+\varphi_{CC}\right) \quad , \tag{2. 33}$$

where m_{CC} and q_{CC} are the parameters of the linear component, while A_{CC}, B_{CC}, T_{CC} and φ_{CC} are required to define the periodical component. This model has been fit on monthly data from the same sources as the other models illustrated so far, that are American data on corn and ethanol. The fit is very good in the 2008−2011 period, in fact the coefficient of determination is 0.71 with the parameters of the model reported in table 2.11.

Table 2. 11. *Parameters of the corn price forecast function using a periodical with trend component model.*

Parameter	Value	Units
$\mathbf{q_{CC}}$	3.5874	[$/bu]
$\mathbf{m_{CC}}$	0.0486	[$/(bu* number of months since Jan 2008)]
$\mathbf{A_{CC}}$	0.9562	[−]
$\mathbf{B_{CC}}$	0.3057	[−]
$\mathbf{T_{CC}}$	41.7032	[months]
$\boldsymbol{\varphi_{CC}}$	1.0926	[−]

The obtained function has been tested on a wider time span to verify the quality of the parameters and particularly of the periodicity (TCC), whose value was similar to the length of the analyzed period. The comparison with data from the 2005−2011 period provided even better fit (R^2= 0.82), thus confirming the identified parameters.

The same technique can be applied to ethanol price, for which data are available only from a later time, since the approval of the Energy Policy Act that gave rise to bioethanol industry dates to mid−2005 and an appropriate ethanol market was not established before a couple of years.

The ethanol price function is in the form of equation 2.11:

$$EthanolPrice_t=(q_{EE}+m_{EE}\cdot t)\cdot(A_{EE}+B_{EE}\cdot\sin\left(\frac{2\pi\cdot t}{T_{EE}}+\varphi_{CC}\right) \quad , \tag{2. 34}$$

where q_{EE} and m_{EE} are the parameters of the linear component, while A_{EE}, B_{EE}, T_{EE} and φ_{EE} are used to define the periodical component. The regression provides equally good fit (R^2=0.67) with the parameters reported in table 2.12:

Table 2. 12. *Parameters of the ethanol price forecast function using a periodical with trend component model.*

Parameter	Value	Units
q_{EE}	1.8674	[$/bu]
m_{EE}	0.0086	[$/(bu* number of months since Jan 2008)]
A_{EE}	0.9728	[−]
B_{EE}	0.2135	[−]
T_{EE}	41.6922	[months]
φ_{EE}	1.2616	[−]

As expected, ethanol growth rate (m_{EE}) is smaller than corn one, as it represents 0.46% of initial ethanol price, while the growth rate (m_{CC}) is 1.35% of initial corn price, thus confirming once again that ethanol prices are growing slower than corn ones.

Furthermore, it is interesting to notice that the periodicity is the same between the two commodities ($T_{CC} \approx T_{EE}$) and that they are almost synchronized ($\varphi_{CC} \approx \varphi_{EE}$). This may be linked to the fact that corn and ethanol price series are highly correlated (note that each one is highly correlated with oil, so they are correlated each other).

2.5.2 Results and comparison

An interesting feature of this forecasting technique is that it allows to predict future prices without having recourse to other commodities, thus limiting the uncertainties and the only input is the following time values. The calculated quotations of corn and ethanol are plotted in figures 2.27 and 2.28 respectively. Figures 2.27 and 2.28 allow also to compare the calculated values with historical data.

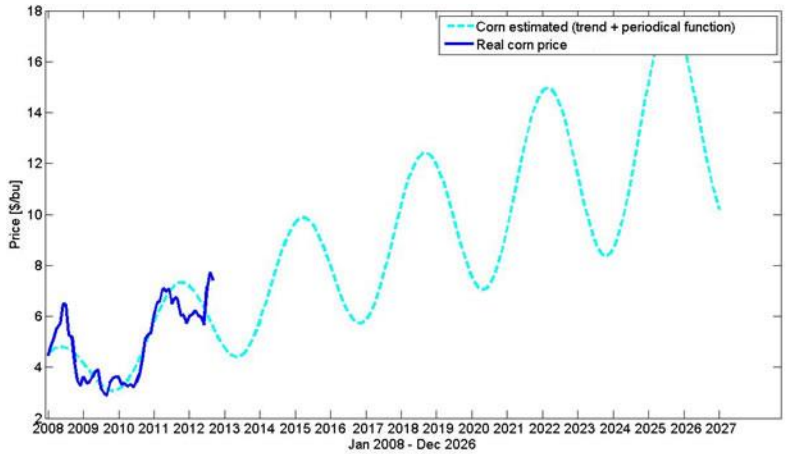

Figure 2. 28. *Calculated corn price using a periodical with trend component model (light blue) compared with real corn price (dark blue).*

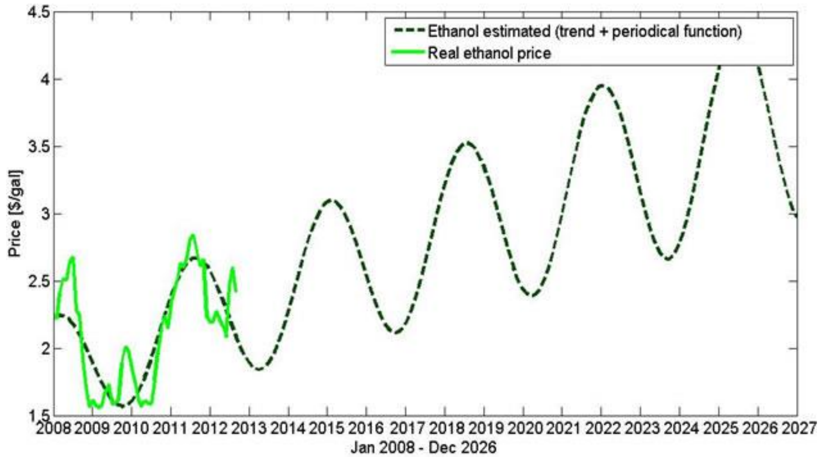

Figure 2. 27. *Calculated ethanol price using a periodical with trend component model (dark green) compared with real ethanol price (light green).*

Finally, the estimated average prices in the periods of interest are reported in table 2.13:

Table 2. 13. *Forecasted corn and ethanol prices using the periodical with trend component model.*

Forecasted good	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Corn price [$/bu]	6.21	7.83	9.77	11.91	13.87
Ethanol price [$/gal]	2.30	2.59	2.95	3.35	3.71

Ethanol price is expected to grow from 0.66 €/kg up to 1.03 €/kg while corn is expected to reach 420 €/t in the last period.

2.6 Final Remarks

The models that have been introduced in this chapter will be used to provide the supply chain simulations with realistic commodities prices for the whole operative life of the supply chain. The forecasted corn and ethanol prices until 2026 are resumed in tables 2.14 and 2.15.

Table 2. 14. *Average forecasted price of corn according to different models.*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Forecasted corn price using the ADL model [$/bu]	8.78	11.35	14.24	17.04	20.09
Forecasted corn price using the fully stochastic model [$/bu]	6.65	8.25	10. 50	13.09	16.30
Forecasted corn price using the linear model with oil−related fluctuations [$/bu]	7.74	9.79	12.20	14.17	16.61
Forecasted corn price using the periodical with trend component model [$/bu]	6.21	7.83	9.77	11.91	13.87

Table 2. 15. *Average forecasted prices of fuel−grade ethanol according to different models.*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Forecasted corn price using the ADL model [$/gal]	2.43	2.60	2.77	2.85	3.01
Forecasted corn price using the fully stochastic model [$/gal]	2.07	1.97	1.87	1.77	1.70
Forecasted corn price using the linear model with oil−related fluctuations [$/gal]	2.66	3.03	3.47	3.82	4.26
Forecasted corn price using the periodical with trend component model [$/gal]	2.30	2.59	2.95	3.35	3.71

The design of supply chains according to different price evolution models is conceived to evaluate the impact that price evolution dynamics would have on its economic performance. In the next chapter, the calculated prices will be adapted to the Italian context, on which the supply chain design is based, and the price evolution of other commodities related to bioethanol production will be estimated (§ 3.1). Then, it will be tested whether the supply chain is robust to changes in the future trend of commodities prices (§ 3.2) and how consumers will be affected by changes in price evolution dynamics (§ 3.3).

Chapter 3

First generation ethanol market dynamics and impact on supply chain layout

Corn−based ethanol supply chain is impacted by a number of factors, notably commodities and co−products prices, demand levels and regulations. To begin with, general features of the corn and ethanol market will be introduced (§ 3.1), including a study about ethanol process co−products. Then, supply chain will be deployed using the results of price forecast models (§ 3.2) to assess its robustness to different price evolution dynamics. Finally, the profitability of supply chain will be assessed, comparing that with historical data and introducing observations about the impact of biofuels on taxpayers and consumers (§ 3.3).

3.1 General corn and ethanol market dynamics

3.1.1 Pressure on corn stocks

In this paragraph a study to partially assess the causes of the rise in corn price as a result of supply and demand dynamics is presented. This has been done because corn accounts for the majority of the costs to produce bioethanol by the dry grind process (Kwiatkowski et al., 2006). First, global supply and demand drivers for corn during next years have been investigated, then an elasticity value to link the increase in demanded quantity to a corn price increase has been searched and finally the minimum impact on corn prices caused only by the supply and demand dynamics has been calculated.

Data about the increase in demand and supply for next years have been found on different reports (USDA, 2012; FAPRI-ISU, 2011; FAO, OECD, 2011). The study has been conducted on a global scale, since corn market is tightly interconnected and dynamics are similar all around the globe. Main demand drivers for corn are bioethanol production, for which policies have been set all over the world, and fodder demand for the increased meat consumption by emerging countries. Supply is also expected to increase because yield in emerging countries can be increased by technological improvements and fertilizers, while it has to be considered also that high corn prices promote the conversion of land from other crops to corn.

Eventually, demand is increasing at a higher rhythm than supply and global corn stocks are going to be stressed and to diminish accordingly. This behavior has been recorded also in last years and is likely to increase in magnitude in future. Ending stocks for 2012 recorded historically low levels, also because of a severe drought that reduced the harvest in the United States, the world largest producer. The reduction of stocks indicates that yearly production is not able to balance demand; therefore prices are expected to rise. Figure 3.1 reports the forecasted ending stocks on yearly production as elaborated from FAPRI−ISU data (2011).

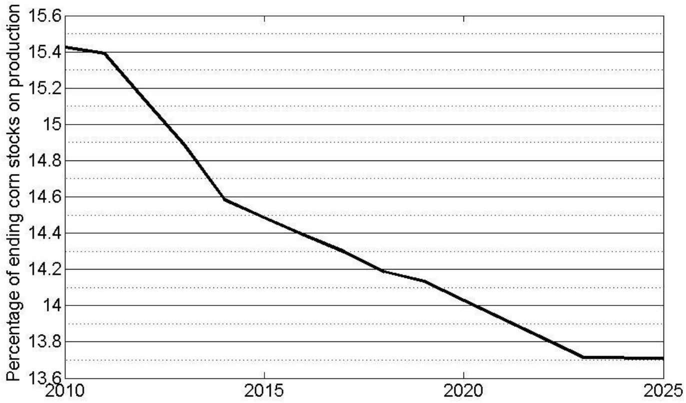

Figure 3. 1. *Ending corn stocks as percentage of yearly production (elaborated from FAPRI-ISU 2011 data).*

In order to quantify corn price growth due to reduction in corn stocks, the elasticity value of corn price increase on corn supply was needed, to link increased demand to prices as in equation 3.1 (elaborated from Luchansky and Monks, 2009).

$$log\left(\frac{Q1}{Q2}\right) = \varepsilon \cdot log\left(\frac{P1}{P2}\right) \quad , \qquad (3.1)$$

where ε is the elasticity value, Q1 and Q2 are two quantities of produced corn−based ethanol and P1 and P2 are corn prices under the same conditions.

Actually, the need to forecast corn price increase as a consequence of corn−based ethanol production arose since the approval of the Energy Policy Act in the United States (2005). Nevertheless, few models were able to predict the huge expansion of American fuel−grade ethanol production capacity and so they were not able to correctly forecast corn price increases. Notwithstanding, some studies agreed on a value of corn price elasticity on ethanol production of around 0.5. In fact Luchansky and Monks (2009) propose 0.548, while Park and Fortenbery (2007) suggest 0.447.

If the elasticity value is applied to the proportional decrease in corn stocks according to equation 3.1, the corn price increase as a result only of pressure on corn stocks is obtained.

For instance, the 2012 production will be used for 84.9% instead of 84.6% in 2011, therefore this increase in demanded quantity makes the 2012 average price 0.6% higher than 2011 price, if equation 3.1 is used with the elasticity value of 0.548 as proposed by Luchansky and Monks.

The calculation can be extended to all the years for which a prediction on the reduction of ending stocks is available. Notably, it has been possible to determine the price increase on 2011 levels for all the time periods of interest. The expected price increases are reported in table 3.1.

Table 3. 1. *Corn price increase caused only by the pressure on corn stocks.*

	2012−2014	**2015−2017**	**2018−2020**	**2021−2023**	**2024−2026**
Corn price increase due to pressure on corn stocks (on 2011 value)	1.13%	2.17%	2.76%	3.65%	3.66%

The corn stocks reductions have been calculated from the FAPRI−ISU estimates (2011), which are in good accordance with the other abovementioned sources. It is noticed that since 2023 the corn stocks are expected to stay almost constant (13.71% in 2023 decreasing to 13.70% in 2025 and 2026).

The results of this analysis can be regarded as the "minimal increase" of corn prices in each period, because this study is focused only on one factor that determines corn price, while many others are neglected. Furthermore, all the data used for those projections are estimates, and an unexpected event (such as a favorable biofuel policy in a key country or the unfulfilled productivity increase) can upset the forecast.

If the predicted corn price increases of table 3.1 are compared with the predictions by the models discussed in chapter 2, we can see that a significantly lower increase is forecasted in this case: that is clearly due to the different modeling assumptions but also to the fact that those models have been tuned on the past U.S.A. trends, whereas this case is based on global projections.

Furthermore, two comments have to be underlined about corn price elasticity:

a) Corn price elasticity value is uncertain;
b) Elasticity value in the source articles was used only to compute the corn price increase related to an increase in corn−based ethanol demand, and it could be inappropriate to extend its use beyond the original range of applicability.

Finally, this study can be used as a qualitative description of the effect of supply and demand dynamics on global scale for the corn market, but it may fail to provide realistic predictions for the supply chain design.

3.1.2 Price adaptation to Italian context

All the designed models have been tuned on United States data, as illustrated in § 2.1.2. but the final goal of the simulations is to provide the ideal bioethanol supply chain layout in Northern Italy, therefore price adaptation to the Italian context is necessary.

The straightforward conversion from American units to European ones of historical prices gives rise to some observations. In fact, considering 2011 average prices, Italian corn price (Associazione Granaria di Milano, 2012) is equivalent to the converted American one, while ethanol price (ICIS, 2012) is 15% higher than converted American one.

The reason of this difference can be explained by analyzing the international markets of the two commodities. In fact world corn export market is very concentrated, with United States as the main actor (Abbassian , 2006), so an “international reference” corn price can be set, and notably this is referred to as the Chicago trade price (USDA ERS, 2012). That is further demonstrated by the very high correlation of the dynamics of Italian and EU corn price with the American one (Ferrazzi, 2008). Eventually the structure of global corn market confirms that prices forecasted by chapter 2 models, based on United States prices, can be reasonably applied to all net−importer countries, and Italy is one of them (ASSOSEMENTI, 2012).

For what it concerns fuel−grade ethanol, historical European fuel−grade ethanol prices have always been 15%−20% higher than American ones, so the 2011 difference is aligned with those data and it can also be justified by the configuration of world ethanol market.

In fact, no world−scale market for ethanol does not exist, since this commodity is subjected to many import restrictions, that are quotas and import duties, such as in the European Union for ethanol (BEST, (BioEthanol for SustainableTransport), 2009) and gasoline−ethanol blends (Kfouri, 2011), and, until end 2011, also in the United States against Brazilian ethanol (US Energy Information Administration, 2012).

Furthermore, the United States technological conditions are different from the Italian ones, because of the higher maturity of American bioethanol industry.

Therefore it was chosen to use for the Northern Italy supply chain simulations:

(i) As corn price, the converted American corn price (using 2011 average conversion rate from dollars to euro) predicted by the models;

(ii) As ethanol price, the converted American ethanol price predicted by the models, increased by 15%.

3.1.3 Bioethanol by−products prices

Two important by−products are related to the ethanol production processes based on corn, that are Dried Distillers Grains with Soluble (by now DDGS) and electricity.

DDGS are used as animal fodder with nutritional properties similar to soybean (Tonsor, 2006), and they are obtained from the classic Dry Grind Process, on which most American plants are based, in the same quantity as ethanol. DDGS are only marginally present in the Italian market (Flake, 2012), so it is necessary to estimate their price as soon as the bioethanol supply chain is implemented if Dry Grind Process is used.

In order to do that, the DDGS price dynamics in the United States after the approval of the Energy Policy Act were studied. Interesting resources have been found in the Iowa University literature (Hofstrand and Johanns, 2012), which shows that after the approval of the Act, DDGS price aligned itself to corn one, fluctuating between 75% and 110% of corn price, as it can be seen in figure 3.2.

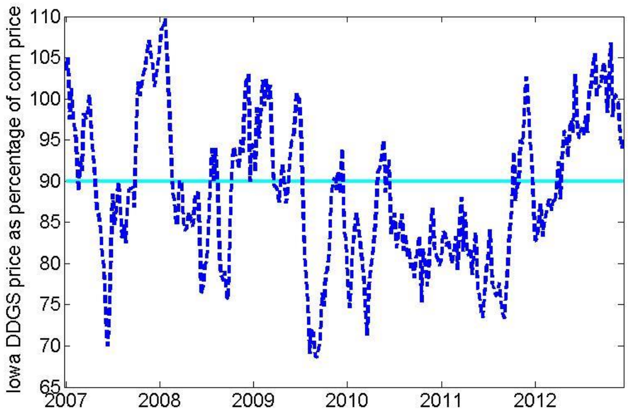

Figure 3. 2. *DDGS price as percentage of corn price in Iowa and mean value in cyan.*

There is not any trend of increase or decrease in this proportional term, neither DDGS price showed decorrelation from corn price when the latter was record−high, so it seems reasonable to consider that the Italian market for DDGS will follow a behavior similar to the American one. Therefore, DDGS price is supposed to link itself to corn price through a constant term that can be set to the average value of the American proportional term, which is 0.90.

Electricity can be produced in CHP (Combined Heat and Power) modules from DDGS combustion and it can be used both for plant's needs and sold to the grid. Other technologies produce electricity from a fermenter module fed by DDGS.

The electricity production from renewable biomass, as in these technologies, can benefit from governmental subsidies, but their exact amount varies all the years. A brand new law has been adopted in Italy for plants producing "green" electricity and it will come into effect during next months (DM 6 July 2012). This law pushes renewable−sourced facilities towards a more "market based" dynamic, where subsides are granted by public auctions in order to diminish the overall subsides burden on taxpayers (eLeMeNS, 2012). This approach is completely different from the "grid buying tariff" that the government has granted until now, so it is impossible to define correctly electricity subsidies in the coming years. According to experts, subsides will lower by around 15%−30%, but the strongest decrease in subsides will be aimed to facilities using non−waste materials for producing renewable electricity, thus a decrease of subsides by 15% can be considered reasonable for the above described plants that use DDGS . The granted subsides are expected to be maintained for a long period, as it has been the case for the previous policy. For this reason, it seems legitimate to use current subsides level (200 €/MWh) for the 2012−2014 period, then to decrease them by 15% and keep them constant until 2023, while in the last time period (2024−2026) they will be lowered by an additional 15%.

3.1.4 Impact of foreign corn price difference on import strategy

All the supply chain simulations were conducted on the basis on the model developed by Giarola (Giarola, Zamboni and Bezzo, 2011) with modifications as in appendix A.

While corn price has been defined to be equivalent to the American one because of the globalization of corn market (§ 3.1.2), it is interesting to evaluate if the bioethanol plants are supplied by imported corn or by autochthon production. The supply chain design has been simulated according to the model defined in chapter 1 using GAMS ® under different price spreads between autochthon and imported corn prices. The simulations show that it is more remunerative for the bioethanol supply chain to use only imported corn if its price is at least 12 €/t cheaper than the Italian one. On the other hand, if Italian corn costs up to 5 €/t more than imported one, bioethanol production shall be carried out without having recourse to imported corn: in that case logistic costs make the difference. When the price difference is intermediate, part of the corn is imported and part is produced.

The supply chain design simulations that follow will use the original hypothesis of equivalent Italian and imported corn price because the supply chain design is considered a tool for long−term planning, while the discussed choice between imported and autochthon con is useful for operational short−term decisions.

3.2 Supply chain simulations using different commodity prices forecast techniques

3.2.1 Forecasted prices and comparisons with real data

The supply chain layout will be simulated using the four price forecast models, in order to test if the supply chain design is robust to difference in commodities prices evolutions. Nevertheless, in this paragraph the four models proposed in chapter 2 are compared in order to identify the most reliable model, that is the one whose predictions seem to be closer to what the future prices will be.

For that scope, two comparisons are made: in the first, prices obtained with different forecasting techniques are compared with real 2012 average data; in the second, the expected

Compound Annual Growth Rate of the different models for each commodity is compared with its historical value. While it is clear that the comparison based on a very short period could generate the risk of extrapolating future prices without solid bases, this is the only comparison that can be drawn between predictions and real data, because all the models have been tuned on 2008−2011 data, therefore a comparison with real data in this time period seems inappropriate. American corn and ethanol quotations have been averaged for the whole year, with the result that 2012 corn average price can be set to 6.93 $/bu (Hofstrand and Johanns, 2012), with a strong increase from January price (6.01 $/bu) to December price (7.60 $/bu). The same approach has been used for ethanol price, which also recorded an increase but in a smaller extent, since its price rose from 2.14 $/gal in January to 2.43 $/gal in December, with an yearly average of 2.24 $/gal. The price forecast models have been applied to the forecast 2012 quotations, and the results have been compared with the real 2012 prices for both corn and ethanol in table 3.2.

Table 3. 2. *Comparison of forecasted corn and ethanol prices with real 2012 prices.*

	ADL Model	**Fully stochastic model**	**Linear model with oil−related fluctuations**	**Periodical with trend component model**
Corn price difference vs. real 2012 value	−8.6%	−9.7%	−3.5%	−3.3%
Ethanol price difference vs. real 2012 value	−1.8%	−6.3%	+8.4%	+0.4%

All models make little relative errors on the 2012 prices, that is due to the short−term extrapolation from the period on which the models parameters were regressed. Notably, the periodical with trend component model appears to predict commodities prices more accurately than the others.

Another way to compare the model projections is to consider the compound annual growth rate (CAGR), that is the equivalent yearly growth rate, of each commodity and to compare it with the historical one. It is possible to calculate the CAGR of corn and fuel−grade ethanol of last years. Notably, 2011 average corn price is 280% the 2002 average price, that is a CAGR of 12.2%, while the increase in fuel−grade ethanol price is equivalent to a growth by 6% per year since 2005. The predicted growth rates are reported in table 3.3 and they are also compared with the effect of only the pressure on corn stocks as studied in § 3.1.1.

It has to be remembered that the increases are considered in relation to nominal prices, so in real terms the commodities prices increases will be lower, since inflation rate has to be taken into account. More precisely, the 2011 global average inflation rate was 5% and the developed countries average inflation rate was 3% (CIA, 2011).

Table 3. 3. *Compound Annual Growth Rates of the commodity prices as predicted by the models.*

	Corn price CAGR	Ethanol price CAGR
Historical values [1]	+12.2%	+6.0%
Predicted for 2012−2026 by the ADL model	+7.8%	+1.7%
Predicted for 2012−2026 by the fully stochastic model	+8.1%	−1.5%
Predicted for 2012−2026 by the linear model with oil−related fluctuations	+6.6%	+4.0%
Predicted for 2012−2026 by periodical with trend component model	+7.8%	+3.3%
Predicted for 2012−2026 only because of pressure on corn stocks	+0.5%	not applicable

[1]: Corn CAGR is calculated from 2002−2011 data; Ethanol CAGR is calculated from 2005−2011 data

It is encouraging to have models that predict a slower growth rate for both corn and ethanol prices than in last years because the end of American subsides and the decrease in corn−based ethanol profitability (see also § 3.3.1) will halt an important demand factor for the corn market and also for the ethanol one. On the other hand, existing and future policies for biofuels (notably by European Union and China) are likely to support ethanol market, and also corn price is likely to grow, in part because the abovementioned pressure on stocks and increased demand as animal fodder.

The periodical with trend component model forecasts price growing rates that are about 60% of the historical ones, which seems an appropriate increasing trend, while the fully stochastic model showed the strongest underestimations of commodities prices and also it predicts a decrease of ethanol price by 1.5% per year, which seems to be far from reality.

The two "explanatory" models (i.e. the ones that explain the commodity behavior linking it to oil price), show each one big difference with one commodity and good fit with the other (as it can be seen from table 3.2), probably because the models have been tuned on the 2008−2011 period, which has been marked by a first year of crisis and the three others of strong economic recovery in the U.S.A., therefore the models incorporate an endogenous growing trend of economy (and consequently of oil price), that conflicts with real 2012 economic data on world scale.

In conclusion, the obtained values from the periodical with trend model and the linear model with oil−related fluctuations are considered the ones which can better forecast the average trend of the commodities prices in the periods of interest, but the supply chain has to be tested under all the price evolution paths to prove its robustness to changes in price dynamics.

3.2.2 Supply chain layout under current prices and demand configuration

The objective of the following analysis is to compare the supply chain layout under the different price evolution models, in order to prove that investors incur minimal risks if the commodities prices follow one price evolution path or the other. It will be shown that different commodities prices forecast techniques provide similar supply chain layouts, while the economic performance of the supply chain is not dramatically altered if prices will be closer to the forecasts of one model or the other. The model by Giarola et al. (2011) has been adapted in order to include commodities and by−products price variations, and then it has been tested under the forecasted price conditions and the new co−products quotations (§ 3.1.3). The bioethanol demand level was set as according to current legislation (European directives 98/70 and 2009/28) in order to gradually reach the 20% content in fuel in 2025.

The Net Present Value (that is the sum of the discounted cash flows of all the periods) of the whole supply chain is widely negative whatever the prices evolution dynamics is, thus indicating that the bioethanol production is not a profitable business at the predicted price levels and under the currently demanded quantities.

This can be easily understood when comparing the raw materials purchasing costs with the selling price of the product (i.e. ethanol). In fact, if a standard yield of 2.8 gallons of ethanol per corn bushel is considered (Nghiem, 2008), biomass purchasing cost is higher than the selling price in all the four models in most of the periods. For instance, in the last period, the periodical with trend model predicts corn price to be 13.87 $/bu, thus the raw materials costs 4.95 $/gal of ethanol, which is 34% more than ethanol forecasted selling price (3.71 $/gal).

Furthermore, the model has been extended to include four additional plant technologies, based on the fermentation of grain residuals either as whole stillage or as thin stillage (the latter technology allows also a small production of DDGS). In both cases additional inputs for electricity production can be either more stillage, bought for the purpose, or natural gas for the CHP (Martin et al., 2012). As expected, when corn prices rise very high, the technologies involving the DDGS sale (that are Dry Grid process and Thin Stillage) are preferred. It has also been simulated the case in which the linear relationship of DDGS price with corn price is maintained only until the historical maximum corn price, in order not to use this relation outside its range of applicability. This peak corresponds to about 230 €/t, and above that value DDGS price is supposed to stay constant, as if above that price soybean and other fodders are expected to be preferred to DDGS: this would be supported by the fact that soybean as fodder and alfalfa are currently quoted in Italy at about 230−240 €/t (Associazione Granaria di Milano, 2012). In this case the CHP technology is preferred to the technologies that involve DDGS sale and it is present in all simulated supply chains.

The precise location of the ethanol plants and corn crops depends heavily on the price difference between Italian and imported corn, so any single solution cannot be shown. If there is not any price difference, plants are located close to main blending centers but also not far away from the most corn producing regions. They are predicted to be placed close to Milan and Venice, but also to important transportation nodes (e.g. Porto Viro and Trieste), and crops are located in the neighbor zones (Novara, Milan, Eastern Veneto, Porto Viro, Ferrara, Udine). On the other hand, when the price difference between imported corn and autochthon one is appreciable, plants are located close to main import hubs, in order to facilitate the import of corn and the transportation of produced ethanol along the Po river axis and main railroads. In this case, plants are located in the Porto Viro region and Ferrara, while corn is either completely imported (when price difference is greater than 12 €/t) or partially: in the last case, Eastern Veneto contributes with a consistent production and a plant is therefore located in the Venice area.

Figures from 3.3 to 3.6 illustrate the supply chain layout in 2024−2026 according to the four price prediction models, and in each figure the description of the preferred plant technologies and the Net Present Value of the configuration is reported. In all simulated cases, Italian and imported prices are the same and DDGS are considered to follow their historical link with corn price, even at higher prices than historically reached.

It is worth noticing that very small changes appear between the different solutions, which relieves the investor from dramatic changes when the supply chain is already established if commodities price evolve in a different manner. The predicted supply chain layouts are therefore robust if the price dynamics changes, but each single design is economically optimal under the underlying price hypotheses.

In all simulations the Po river allows the transportation of ethanol produced in eastern Italy towards Milan or Genova demand centers, while the Ravenna terminals are also supplied by the Porto Viro plant and the one located in the North−East, that is either close to Venice (thus using Venice harbor for transportation) or close to Udine (in this case Trieste harbor is preferred). An important plant is also located in the Milan− Turin region and provides part of the ethanol require by the Western Italian demand centers.

It is also worth noticing that in all the simulations three plants are built, two bigger ones (which reach 350 kt of ethanol per year in the last period) and a smaller one, that is built in the 2018− 2020 period, that reaches 265 kt of ethanol per year.

The two first price evolution scenarios never allow the supply chain to earn money, while the linear model with oil−related fluctuations and the periodical with trend one predict positive cash flows until 2016 but in all the cases the global return on the investment is negative.

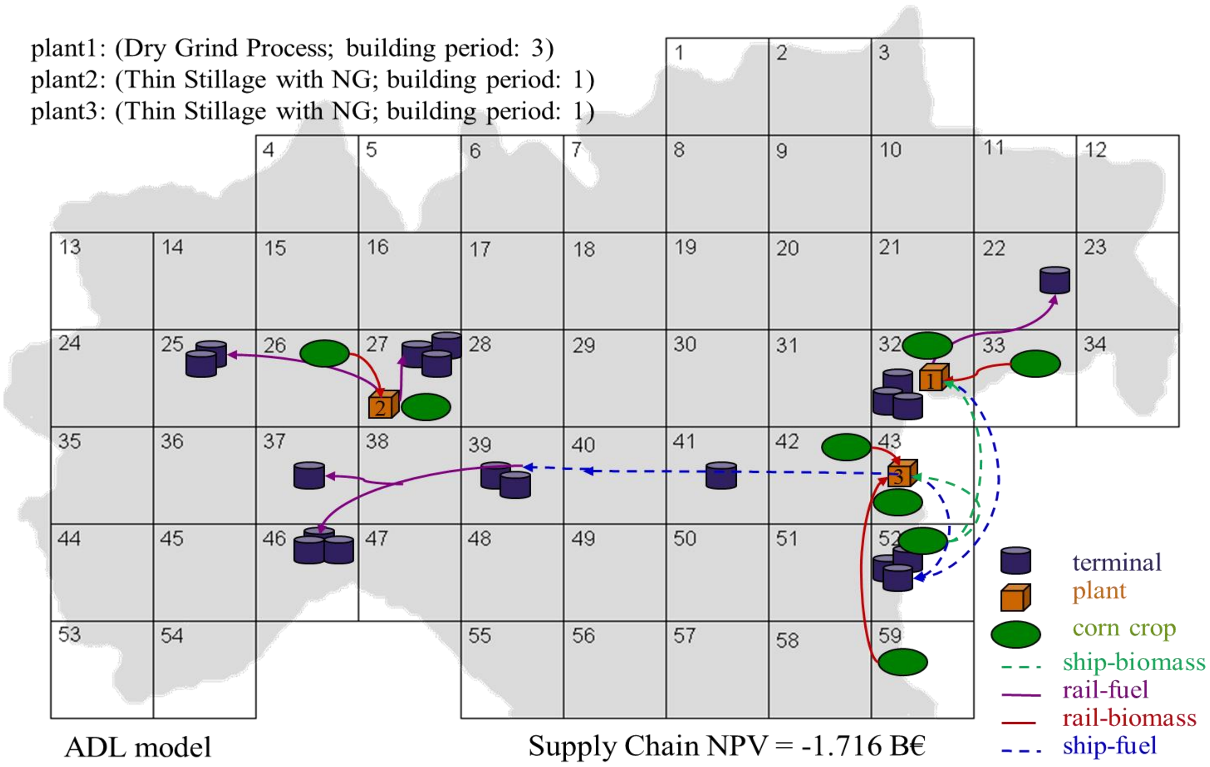

Figure 3. 3. *Supply chain design using the forecasted prices by the ADL model.*

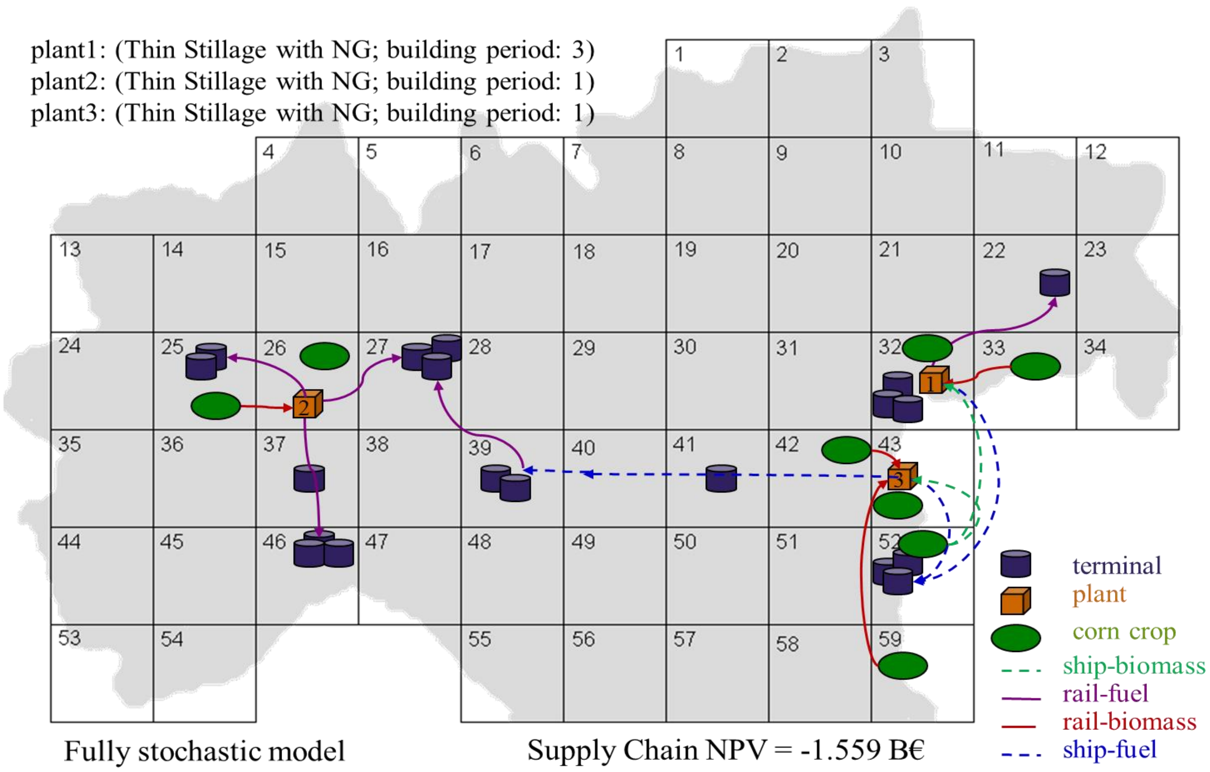

Figure 3. 4. *Supply chain design using the forecasted prices by the fully stochastic model.*

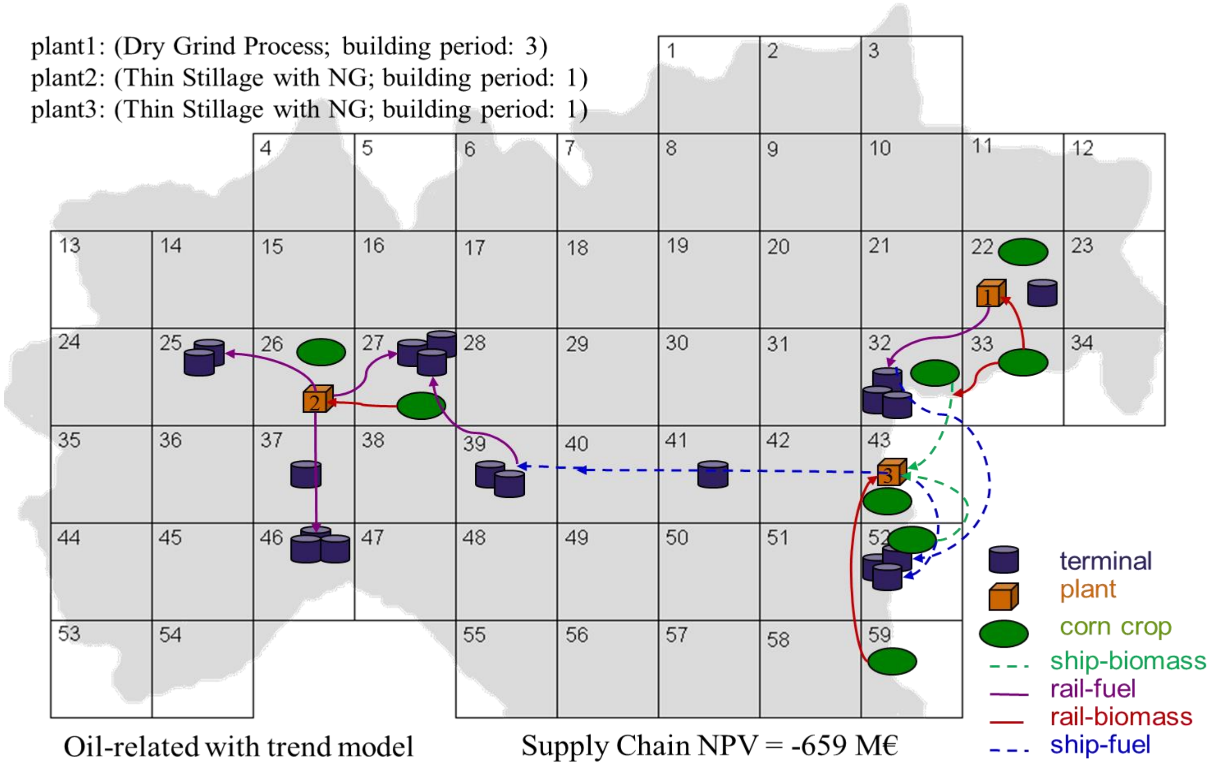

Figure 3. 5. *Supply chain design using forecasted prices by the linear model with oil-related fluctuations.*

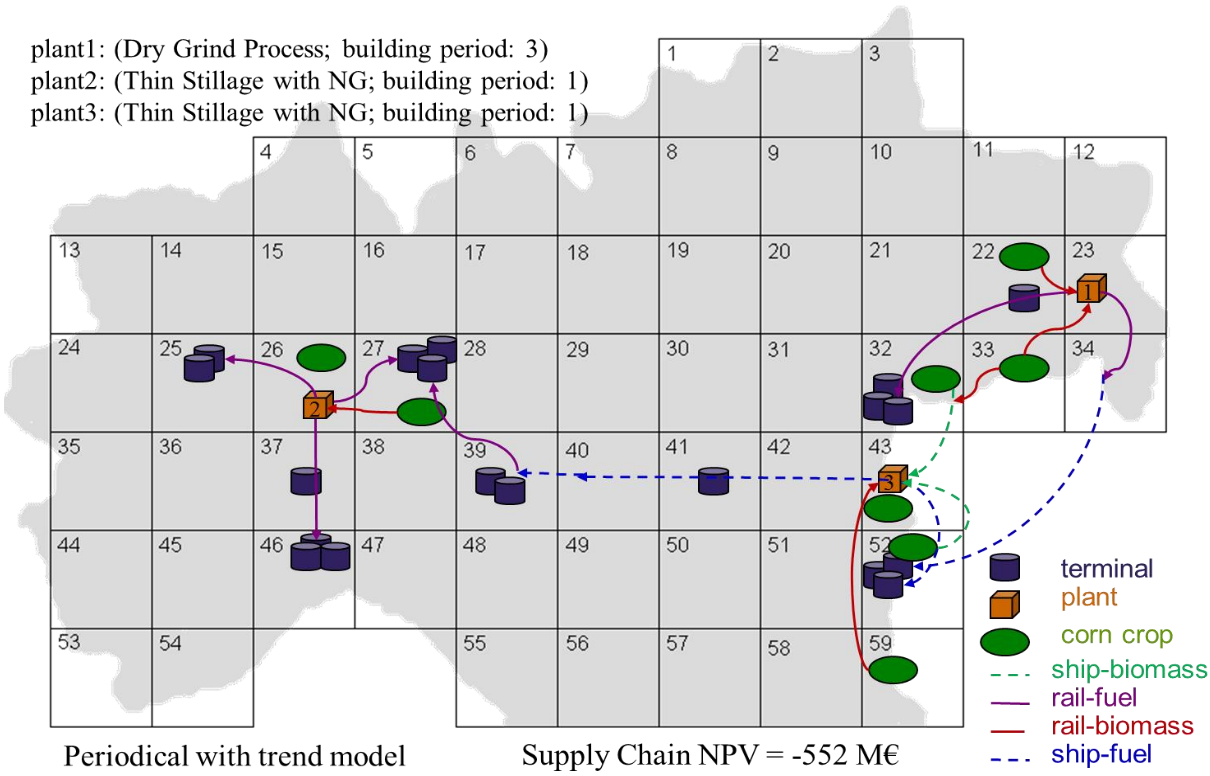

Figure 3. 6. *Supply chain design using forecasted prices by the periodical with trend model.*

3.2.3 Supply chain layout under different demand scenarios

The very low profitability of the previous supply chain configurations can be caused either by the very high raw material costs compared with low products selling prices or to the high demanded level that constrains the plants to produce even in not profitable configurations. While the first factor cannot be modifies, as it is the output of the price forecast models, the second one can actually be reconsidered in two different demand scenarios

A first re−arranged demand scenario is the one that considers that the European Commission Proposal (European Commission, 17/10/2012), that amends the existing directive, actually takes place. This demand scenario needs an extensive review and dedicated studies for the other bioethanol production technologies that are related. For this reason entire chapter 4 is devolved to this study.

A second modified−demand scenario is the one that supposes that supply chain operates only when it is profitable to produce ethanol, thus without being constrained to match the bioethanol demand. In fact companies are not obliged to blend ethanol that is produced in Italy and it may be more profitable for them to buy foreign ethanol (despite the high import taxes) instead of establishing a dedicated supply chain. According to this scenario the supply chain is operated only if it produces ethanol without making losses, and the depreciation costs are carried over along the whole lifecycle of the plants, regardless on the effective use. A dedicated supply chain model has been designed by further modifying the Giarola model (2011). It has not been possible to define the cost of importing ethanol mainly because of the variability of the import restriction strategies, but it has been simulated the operating time of the supply chain when it is profitable, according to forecasted prices.

The simulations provided an interesting result. In fact, the costs for opening the plants could never be recovered by the produced cash flows, thus the simulator suggests to never operate the supply chain if the price conditions are the ones predicted by whatever the prices forecast model. In fact the supply chain’s revenues are never able to exceed the operative expenditures plus the periodically equivalent capital investment.

3.3 Supply chain profitability

3.3.1 Analysis of historical profitability

The unprofitable results of the supply chain designs according to the forecasted prices configurations is worrying about the ethanol industry itself, so it has been considered important to assess the profitability of the supply chain in the past.

In order to do that the updated Giarola model has been used to simulate supply chain profits under different price conditions, thus it has been possible to determine the breakeven corn and ethanol prices and to finally draw the profitability breakeven curve as the union of those prices. The breakeven curve is used in figure 3.7 to separate the region whose prices make the supply chain profitable from those that make it not, that is the maximum corn price that has to be paid to make profits, once known the ethanol price. It is obvious that the curve depends on the chosen technology, so it has been determined under the best configurations at every price level by compared optimization of all the selected technologies.

The breakeven curve has been compared with the European equivalent (as in § 3.1.2) of the yearly average corn and ethanol prices since 2005 in the same figure 3.7.

It is interesting to notice that once the ethanol supply chain in the United States was consistently established (2007−2008), the additional corn demand by bioethanol pushed the price points closer to the breakeven curve, thus strongly contributing to affect profitability. From 2011, the rise in corn prices determined the non−profitability of the supply chain, and the trend was confirmed in 2012. Any major issue was raised in 2011 since the 0.51$/gal subside was still in force, thus shifting upwards the breakeven corn price.

On the other hand, many business reported losses in 2012 because of the price configuration and of the end of governmental subsidies (IEA, 2012; NACS, 2012).

In order not to burden on the final consumers, either the supply chain is run when it is profitable (see § 3.3.2) or it is subsided by government (whose investment is estimated in § 3.3.3).

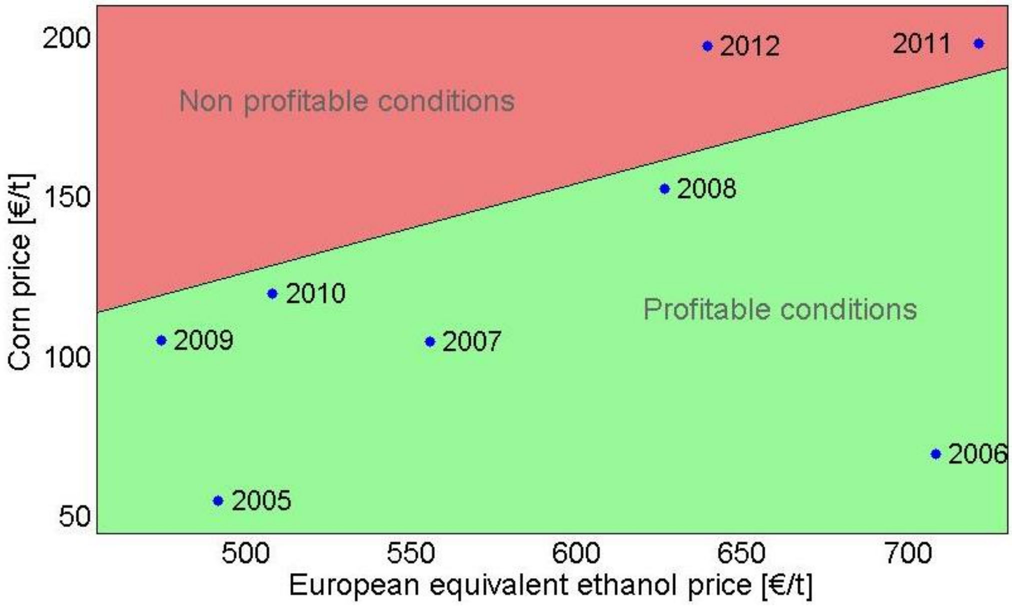

Figure 3. 7. *Yearly average profitability at European price conditions of the bioethanol supply chain.*

Similar studies have been conducted in the U.S.A. to predict the breakeven corn price under different crude oil price scenarios (knowing that ethanol price is related to gasoline and therefore to oil price). It is relieving to notice that different studies are in good accordance with each other (BioPact, 2007; Tyner and Taheripour, 2008). For instance, if crude oil price sets at 80$/bbl, bioethanol production is profitable only if corn is bought at less than 3.7 $/bu (~110 €/t), while if crude oil price rises to 100$/bbl, breakeven corn price is at about 130 €/t. The American government subsidy allowed that, with crude oil at 100 $/bbl, corn breakeven price rises to 180 €/t.

This is a further confirmation that 2012 bioethanol production has not been profitable or only very little profitable, since corn price never went below 190 €/t (reaching hikes at 270 €/t) and oil price ranged in the 90−100 $/bbl.

3.3.2 Conditions for a profitable supply chain

It has been assessed that the bioethanol supply chain is not profitable under current prices configuration nor under forecasted prices for the next years. Since the current prices trend is endogenous in all the forecast models, it has been studied what is the maximum corn price at which the supply chain can start to operate with profits. The behavior of prices for the successive years is still based on the existing models and it reflects the same relative variations along the time periods as in the previous models

That is equivalent to consider the corn price trend as correct, but the values have been rescaled on a new “starting price” that is the one at which the decision to run the supply chain is taken. Ethanol prices have been assumed to remain fixed at the forecasted values.

The purpose of this analysis is to define the corn price that allows to take the decision to run the supply chain from the following year, once assured that the ethanol prices follow the expected trend and corn price grow show good fit with a forecast model.

For this reason, the breakeven starting prices have been calculated for all the forecast model and under the three demand scenarios (see also § 3.2.2):

(i) Ethanol demand under current legislation;

(ii) Ethanol demand as to run a profit−making supply chain

The results of the simulations are presented in table 3.4:

Table 3. 4. *Maximum corn starting price under different price growth models and demand scenarios.*

	ADL Model	Fully stochastic model	Linear model with oil−related fluctuations	Periodical with trend component model
Maximum corn starting price under current demand	93 €/t	88 €/t	140 €/t	146 €/t
Maximum corn starting price for profit−making SC	104 €/t	106 €/t	142 €/t	150 €/t

It can be seen that the profit−making supply chain configuration can operate at higher corn prices according to all the price forecast models, because the ethanol output is not fixed and it can predict fewer plants to open in order to better share fixed costs. As expected, if ethanol prices follow the forecasts by the fully stochastic model, which are lower than the ones by other techniques, a lower starting corn price is needed in order to be profitable. On the other hand, it is confirmed that, if commodities prices follow the predictions by the periodical with trend model, corn price that determines a profitable supply chain is significantly higher.

3.3.3 Required subventions and proposed fuel pricing policy

If the supply chain operates at the forecasted market configurations (§3.2), the required amount to make it run will be transferred to gasoline consumers or to taxpayers, who will have to compensate for the SC losses. If the total supply chain losses are to be covered by governmental subsidies, their amount per period is calculated as in table 3.5. The total equivalent in current terms is added, that is the sum of the subventions in 2013−equivalent euros, discounted at the 15−year Italian government bond (4.70% in January 2013).

Table 3. 5. *Total 1st generation ethanol required subsidies under the current demand scenario and the different price paths forecasted by the models.*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026	Total equivalent in current terms[1] (M€)
Total subsides with prices following the ADL model (M€)	166	613	1216	1971	2901	4600
Total subsides with prices following the fully stochastic model (M€)	317	384	1091	1875	2880	4380
Total subsides with prices following the linear model with oil−related fluctuations (M€)	252	160	518	763	1183	1970
Total subsides with prices following the periodical with trend model (M€)	198	25	303	518	871	1294

1: Discounted at the 15 years Italian bond rate

In the EC proposal scenario, the amount of the subventions barely halves compared with the current demand configuration. It is worth noticing that the budget for subsidies sets from 2 B€ in the best case (periodical with trend growth) up to 7 B€ (ADL model growth trend) totally in the next 15 years. Those figures have been transferred on a per liter basis and compared with the American subsidy, which was fixed at 51 c$/gal, that is 10.5 c€/liter of ethanol.

Table 3. 6. *Difference of the per liter required subsidy with the American one under current demand scenario and different price paths forecasted by the models.*

	2012−2014	**2015−2017**	**2018−2020**	**2021−2023**	**2024−2026**
Difference with American subsidy if prices follow the ADL model	−25%	+133%	+300%	+475%	+659%
Difference with American subsidy if prices follow the fully stochastic model	+43%	+46%	+259%	+446%	+654%
Difference with American if prices follow the linear model with oil−related fluctuations	+14%	−39%	+70%	+122%	+210%
Difference with American subsidy if prices follow the periodical with trend model	−11%	−91%	+0%	+51%	+128%

It can be seen that the expected subsidies are larger than the American ones, but in the case prices will follow the periodical with trend model, this difference will not be more than 27% on average (weighted by the produced ethanol).

Government can include subsidies in the new blended fuel, so that its price will be composed of:

(i) Gasoline price plus taxes weighted on the volume fraction of gasoline;

(ii) Ethanol price plus VAT (21% in Italy) and the per−liter subsidy to the Supply Chain weighted on the volume fraction of ethanol.

This configuration presents some interesting features:

(i) The subsidies would be paid only by fuel consumers instead that by all taxpayers;

(ii) The per−liter fuel price can be lower compared with gasoline price alone;

(iii) A "buffer" effect that protects the consumer from gasoline price variability is created.

It is interesting to notice that this approach makes the final price of the fuel quite indifferent from the expected ethanol price because if ethanol price reaches higher values (as expected in the linear model with oil−related fluctuations), the supply chain losses will be lower, so the ethanol price (plus TVA) will be high but the governmental subsidies will lower. On the other hand, if ethanol price sets to lower values, the supply chain losses will be significant and therefore the subsidies share will increase, but the low purchase price of ethanol guarantees that the final fuel price will be under control.

When considering gasoline price constant at 1.70 €/l (as in mid−2012) for all the periods, the calculated fuel prices according to the different price forecast models are reported in table 3.7, confirming the expected behavior.

Table 3. 7. *Ethanol cost per liter of blended fuel, subsidies to cover Supply Chain losses and total fuel price in the next periods according to different price paths forecasted by the models.*

		2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
ADL model	**Ethanol cost per liter of fuel (c€/l)**	8.77	10.95	13.26	15.19	17.62
	Subsidies per liter of fuel (c€/l)	0.67	2.44	4.77	7.61	11.05
	Total fuel price (€/l)	1.65	1.66	1.69	1.71	1.75
Fully stochastic model	**Ethanol cost per liter of fuel (c€/l)**	7.46	8.29	8.96	9.44	9.95
	Subsidies per liter of fuel (c€/l)	1.28	1.53	4.28	7.24	10.97
	Total fuel price (€/l)	1.64	1.63	1.64	1.65	1.67
Linear model with oil−related fluctuations	**Ethanol cost per liter of fuel (c€/l)**	9.6	12.8	16.7	20.4	24.9
	Subsidies per liter of fuel (c€/l)	1.0	0.6	2.0	2.9	4.5
	Total fuel price (€/l)	1.66	1.66	1.69	1.72	1.76
Periodical with trend model	**Ethanol cost per liter of fuel (c€/l)**	8.29	10.90	14.14	17.86	21.72
	Subsidies per liter of fuel (c€/l)	0.80	0.10	1.19	2.00	3.31
	Total fuel price (€/l)	1.65	1.64	1.66	1.68	1.71

It has to be noticed that in the first period fuel prices do not differ much the one from the other, mainly because the short−term differences in the ethanol price extrapolation is little. The lower prices compared with gasoline in some periods are due to the fact that ethanol price per liter plus the subsidies in that period make this fuel cheaper than gasoline, thus making the blending favorable under the economic point of view. The increase in the ethanol cost per liter of fuel is due to the larger amount of ethanol blended in the fuel and to the fact that most models predict ethanol price to increase.

It has to be remembered that the blended fuel has an inferior Heating Value than normal gasoline, because ethanol Lower Heating Value is about two thirds of gasoline’s one.

Nevertheless, ethanol has an higher octane rating (RON = 113), thus the loss in heating value can be partly counterbalanced by the increase in engine performance. Since this increase in engine performances is difficult to be calculated, it has been decided to take a conservative point of view and to analyze the cost of fuel to consumers on an equivalent mileage basis only due to the diminution in LHV.
Table 3.8 reports the calculated fuel prices differences for the equivalent mileage as one liter of gasoline, always considering the gasoline price constant at 1.70 €/l.

Table 3. 8. *Price difference of blended fuel with 2012 gasoline for the equivalent mileage under different price paths forecasted by the models.*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Fuel price difference with gasoline at equivalent mileage if prices follow the ADL model	−0.3%	+1.0%	+2.9%	+4.9%	+7.6%
Fuel price difference with gasoline at equivalent mileage if prices follow the fully stochastic model	−0.8%	−1.1%	−0.1%	+1.1%	+2.8%
Fuel price difference with gasoline at equivalent mileage if prices follow the linear model with oil−related fluctuations	+0.4%	+1.0%	+3.3%	+5.2%	+8.1%
Fuel price difference with gasoline at equivalent mileage if prices follow the periodical with trend model	−0.5%	−0.4%	+1.2%	+3.1%	+5.3%

It can be noticed that the differences with gasoline price are very small at the beginning, then they increase with the increase of ethanol part in the fuel, that determines a decrease in the fuel LHV, and with the evolution of ethanol price, that tends to increase according to all the price forecast models.
If gasoline price increases, the ethanol share in the fuel guarantees that consumers are not completely impacted by the gasoline price augmentation: in fact biofuels take up a “buffer role”. In order to do that, Italian gasoline price has been simulated for next years, and the final fuel price calculations were updated with the obtained values. Then, the results have been compared with the above presented case of no gasoline price increase.
Gasoline price is made up of three components:

(i) Raw materials plus margin, related mainly to oil price, €/$ exchange rate;
(ii) Excise tax, which is an additive component and is imposed by government;

(iii) VAT (Value Added Tax), which is proportional to the sum of the two previous components.

The growth trend of each one has been simulated in order to have a robust approach for estimations. Raw materials prices and margin do not strictly depend on oil price trend, which has been simulated in § 2.2.3, because euro−dollar exchange rate is also very important, since crude oil is traded in the last currency. The stochastically simulated intermediate trend (§2.2.3) provides a conservative increase rate for next years (about 1% per year) and the expected decrease in gasoline consumption (Unione Petrolifera, 2012) in correspondence with the current strong euro, do not give room to disprove these forecasts.

Excise taxes currently account for more than the raw material prices and margins (Governo Italiano, 2013) and the same is reported for gasoline prices in the last decade. Their increase has been modest in the last ten years (from 52.03 c€/l in 2011 to 56.40 c€/l in 2010), but in 2012 they skyrocketed at 72.84 c€/l. For the future it has been supposed that the historical trend is maintained but starting from the current excise taxes value.

VAT has recently augmented to 21% and it has already been defined its further increase to 22% in 2014. It seems to be probable that it would be increased once again by 2026, at least according to last government proposals.

Average gasoline price predictions are reported in table 3.9.

Table 3. 9. *Predicted future gasoline prices.*

	2012−2014	**2015−2017**	**2018−2020**	**2021−2023**	**2024−2026**
Gasoline average price (€/l)	1.773	1.853	1.948	1.980	1.985

The blended fuel price increases accordingly, but as long as the ethanol component is cheaper than the equivalent gasoline one, final fuel is more economical. Since gasoline price increases, biofuels are convenient until a higher price level. This can be seen in table 3.10.

Table 3. 10. *Blended fuel price difference with predicted gasoline price*

	2012−2014	**2015−2017**	**2018−2020**	**2021−2023**	**2024−2026**
Fuel price difference with gasoline if prices follow the ADL model	−3.2%	−2.8%	−2.1%	−1.2%	+0.5%
Fuel price difference with gasoline if prices follow the fully stochastic model	−3.6%	−4.7%	−4.6%	−4.2%	−3.4%
Fuel price difference with gasoline if prices follow the linear model with oil−related fluctuations	−2.6%	−2.8%	−1.8%	−0.9%	+0.9%
Fuel price difference with gasoline if prices follow the periodical with trend model	−3.4%	−4.1%	−3.5%	−2.7%	−1.3%

Even if the fuel price at equivalent mileage is still more expensive than gasoline (as in the constant gasoline price case), the blended fuel price increase is less that in the former case even by more than 2%, thus confirming the positive “buffer” effect of biofuels blending. This can be seen from table 3.11.

Table 3. 11. *Blended fuel price difference with predicted gasoline price at equivalent mileage.*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Fuel price difference with gasoline at equivalent mileage if prices follow the ADL model	−0.6%	+0.4%	+1.5%	+2.9%	+5.0%
Fuel price difference with gasoline at equivalent mileage if prices follow the fully stochastic model	−1.0%	−1.6%	−1.1%	−0.3%	+1.0%
Fuel price difference with gasoline at equivalent mileage if prices follow the linear model with oil−related fluctuations	+0.1%	+0.4%	+1.8%	+3.1%	+5.5%
Fuel price difference with gasoline at equivalent mileage if prices follow the periodical with trend model	−0.8%	−1.0%	+0.0%	+1.3%	+3.1%

3.4 Final remarks

The bioethanol supply chain design in northern Italy was simulated in this chapter using the commodities prices evolutions as in chapter 2. The supply chain spatial layout was proposed (§ 3.2) and its economic performance was discussed (§ 3.3) under the current demand scenario. Bioethanol supply chain is expected not to have economic interest for an investor, since the Net Present Value of the supply chain is negative whatever the commodities price evolution trend will be, but ethanol blending with gasoline is mandatory according to European laws, therefore the impact of the supply chain establishment on final customers and taxpayers was detailed in § 3.3. The same European Directives that determine ethanol production are currently under review by the European Commission, since in late 2012 the European Commission published a proposal of revision of these directives. Therefore, it has been considered of great current interest to analyze the impact of this proposal on the supply chain layout (§ 4.2) and on its profitability (§ 4.3). In next chapter the supply chain economic performance and the impact on customers will be compared with the current demand scenario and some measures to increase the economic performance of the supply chain will be proposed (§ 4.2).

Chapter 4

Supply chain design implementing the new European Commission proposal

A recently published document by the European Commission proposes to amend some parts of the existing Directive (2009/28/EC) that regulates the demand for biofuels in order to promote more sustainable biofuels. In this chapter we will discuss the content of the EC proposal; then we will analyze the feedstock availability and future price; finally the economically optimal supply chain layout will be presented and commented on. The impact on taxpayers and consumers will also be evaluated and compared with the one provoked by the current demand scenario.

4.1 Review of the EC proposal

The EC proposal of last October (European Commission, 17/10/2012) includes measures to promote the biofuel technologies that do not use food−competitive raw materials and particularly the technologies whose feedstock do not compete with land that can be used for alimentary commodities. Furthermore, second generation technologies, even if not already competitive on an economic basis with first generation ones, produce biofuels with higher GHG saving and higher energy yields (Wang et al., 2012).
The measures proposed by the European Commission do not include any financial help to the second generation technologies, but they develop on two axes:

(i) Limiting first generation biofuels;

(ii) Creating a new accountability technique for the European targets favorable to advanced technologies.

The first is obtained by amending Article 3 of the Directive 2009/28/EC with the following "*the share of energy from biofuels produced from cereal and other starch rich crops, sugars and oil crops shall be no more than 5%, the estimated share at the end of 2011, of the final consumption of energy in transport in 2020*" knowing that the global biofuel use targeted for 2020 is 10% of final energy consumption: that means that first generation fuels shall not exceed 50% of total biofuel production.

The second axis is realized by adding a point (point e) to paragraph 4 of the same article : "*The contribution made by:*

(i) biofuels produced from feedstocks listed in Part A of Annex IX shall be considered to be four times their energy content;

(ii) biofuels produced from feedstocks listed in Part B of Annex IX shall be considered to be twice their energy content;

(iii) renewable liquid and gaseous fuels of non−biological origin shall be considered to be four times their energy content.

Member States shall ensure that no raw materials are intentionally modified to be covered by categories (i) to (iii). The list of feedstock set out in Annex IX may be adapted to scientific and technical progress, in order to ensure a correct implementation of the accounting rules set out in this Directive. The Commission shall be empowered to adopt delegated acts in accordance with Article 25 (b) concerning the list of feedstock set out in Annex IX.", while Annex IX is added as it follows

"*Part A. Feedstocks whose contribution towards the target referred to in Article 3(4) shall be considered to be four times their energy content*

(a) Algae.

(b) Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under Article 11(2)(a) of Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

(c) Biomass fraction of industrial waste.

(d) Straw.

(e) Animal manure and sewage sludge.

(f) Palm oil mill effluent and empty palm fruit bunches.

(g) Tall oil pitch.

(h) Crude glycerine.

(i) Bagasse.

(j) Grape marcs and wine lees.

(k) Nut shells.

(l) Husks.

(m) Cobs

(n) Bark, branches, leaves, saw dust and cutter shavings.

Part B. Feedstocks whose contribution towards the target referred to in Article 3(4) shall be considered to be twice their energy content

(a) Used cooking oil.

(b) Animal fats classified as category I and II in accordance with EC/1774/2002 laying down health rules concerning animal by−products not intended for human consumption.

(c) Non−food cellulosic material.

(d) Ligno−cellulosic material except saw logs and veneer logs."

This new categorization of biomass introduced an accountability technique that can be resumed as:

a) Bioethanol produced from technologies involving a food−competitive feedstock is accounted "as is" for the satisfaction of European targets;
b) Bioethanol produced from technologies involving 2nd generation feedstock from a dedicated culture has to be accounted twice for the satisfaction of European targets;
c) Bioethanol produced from technologies involving 2nd generation feedstock from waste materials has to be accounted four times for the satisfaction of European targets.

This strategy is a zero−budget measure to promote these new and more efficient technologies, but it has the limit to reduce dramatically the potential biofuel production in the EU: in fact it can be theoretically reduced to one quarter of the expected one if European countries will use only waste raw materials.

The supply chain design has been simulated as a Mixed Integer Linear Problem on GAMS ® by providing the solver with four competitive technologies that benefit from different accountability techniques from the recent EC proposal and by constraining the solution to respect the demand scenario defined by the EC proposal. The technologic and economic details related to second generation production facilities are taken from Giarola et al, 2011b. Prices of raw materials have been forecasted in § 4.1.3 except for corn, which has been extensively treated in the previous chapters.

The four technologies which have been included in the model are:

(i) Classic DGP with DDGS sale, with DDGS price linked to corn price as detailed in § 3.1.3;
(ii) Thin stillage process with both DDGS and electricity sale (as briefly presented in § 3.2.2);
(iii) Second generation process based on corn stover as feedstock;
(iv) Second generation process based on a dedicated energy crop, that is miscanthus, which has been proven to be the most promising one in Giarola et al (2011b) by comparison with other energy crops like eucalypthus and poplar.

The simulation model provides the economically optimal supply chain constrained to the EC proposal guidelines: technologies (i) and (ii) cannot produce more than half of the biofuel demand and their production is accounted "as is", while ethanol produced by technology (iii) is accounted four times its real quantity and technology (iv) benefits of a multiplying factor of 2 on its ethanol output.

4.2 Second generation feedstock price forecast

It is crucial for the assessment of the supply chain profitability to understand the future prices of commodities involved. While many other raw materials are used for second generation ethanol processes (Arundo Donax, poplar, switchgrass, eucalyptus), it is unlikely that only one specific feedstock will benefit of technological advancements. Thus, it is reasonable to assume that the selected raw materials (miscanthus and corn stover) are expected to keep their preferred position in the future, at least in the Italian context.

it has to be remembered that Italy, and notably the PO valley, has perfect climate conditions for miscanthus growth (WP21, 2005), so that yield can reach 25 t/ha (VenetoAgricoltura, 2010) compared with about 4 t/ha to 10 t/ha in Northern countries and British islands (Teagasc-AFBI, 2010).

The focus was initially to find out an adequate industrial−level current price for miscanthus, then to forecast its variations during the following years. Big attention arouse recently on miscanthus as energy crop, so various reports were published by governmental agencies, as in Ireland (Teagasc-AFBI, 2010), Agricultural Departments, as in Veneto (VenetoAgricoltura, 2010), Universities, mainly in UK (Hasings et al., 2011), and rhizomes−producing companies (Terravesta, 2012). The sources report different figures about producing costs and selling prices, probably because of their different scopes: for instance it can be seen that the rhizome−producing companies forecast higher selling prices for miscanthus, and that makes the investment in their rhizomes more attractive to farmers.

Many sources agree that miscanthus breakeven cost in northern Italy is currently at about 40 €/t (Biomass Trade Centers, 2009), as tested in some pilot−scale cultivations (e.g. at the agricultural technical institute of Palidano – MN). This is corroborated by the reported miscanthus breakeven costs in places where the yields are lower than Italy, for instance 60 €/t in Ireland (Teagasc-AFBI, 2010) and UK (Hasings et al., 2011). In the U.S.A. the costs are lower, mostly because of cheaper land and fuel, so that the total production cost is indicated at about 40−46 $/t, that corresponds to about 32−35 €/t (Heaton et al., 2012).

The current purchase price is not so easy to be determined since many miscanthus crops are used for self−consumption for heat and power generation. Notwithstanding, it is reported that U.S.A. farmers are willing to sell miscanthus at 60 $/t, which is equivalent to 46 €/t (Schill, 2007), while in Italy the regional Agricultural Department of Veneto proved that Miscanthus dried chips can be marketed like M20 chips, thanks to "*its reduced moisture content and the good quality of the biofuel*" (VenetoAgricoltura, 2010). Therefore, miscanthus chips can be expected to sell at 60– 80 €/t, providing the farmers margins of 100 to 600 €/ha (VenetoAgricoltura, 2010). Without chipping costs it seems reasonable to situate miscanthus selling price to 50−70 €/t. This would confirm the current price reported by a rhizome producer, which indicates the selling price without bailing to 43 £/t, that is 53 €/t (Terravesta, 2012). As a conclusion, it seems realistic that an industrial company can currently buy miscanthus from Italian farmers at 50 €/t. A lower price can be paid if the company itself will participate in miscanthus cultivation (see also § 4.3.2.2).

If current price is difficult to be defined, future prices until 2026 (the studied supply chain lifetime) are even harder to be estimated. In order to do that three ways have been investigated:

(i) literature research;
(ii) estimation of an "energy crops supply curve";
(iii) breakdown of production costs and evaluate their expected trend.

While rhizome producers provide the farmers with forecasts of very high increases of miscanthus selling prices in next years, few independent studies attempt to forecast miscanthus or similar agricultural raw material prices for such a long period. A recent study in the UK reported that in that country energy biomass feedstock breakeven cost is expected to increase by about +25% by 2020 (Panoutsou and Castillo, 2011). If this trend is considered as legitimate also for the Italian context, the 2020 miscanthus price in Italy would be of about 62.5 €/t. As previously mentioned, rhizome producers may have some interest in providing higher selling prices for miscanthus: for this reason, Terravesta expects miscanthus to reach more than 80 €/t by 2020 and 90 €/t by 2023 (Terravesta, 2012). The nature of the source and the fact that these figures are not justified by any report by the company, makes them not completely trustworthy.

The principle of the second approach is to quantify the price increase for miscanthus if an additional demand, caused by Italian bioethanol supply chain, arises. An agribusiness consultancy company proposed an aggregated supply curve at global scale for energy crops (LMC International, 2011), in energy units in order to make all biomasses uniform (the graph is reported in "toe", that is tonne of oil equivalent, equivalent to 41.87 GJ). Once eliminated the extreme values, it can be obtained that if price sets at 150 $/toe, 50 million toe of biomass would be available worldwide, while if prices rise to 350 $/toe, 600 million toe would enter the market, as it can be seen in figure 4.2.

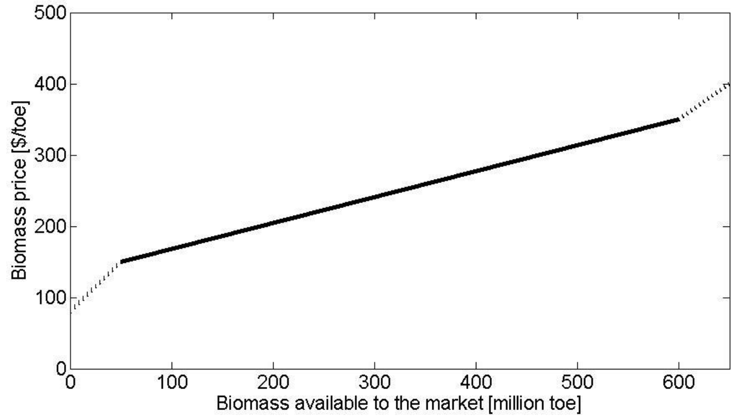

Figure 4. 1 *Aggregated biomass supply curve (elaborated from LMC International, 2011)*

If those figures are used considering miscanthus as the only biomass (whose LHV is 16 GJ/t for an average moisture content feedstock), then it is possible to find the miscanthus price increase for every new tonne demanded in the market. This value sets to $4.09 \cdot 10^{-8}$ €/t^2, that is miscanthus price would increase by $4.09 \cdot 10^{-8}$ €/t for every additional tonne of miscanthus which is demanded. The maximal initial miscanthus demand for ethanol production would be of 3.57 million tonnes in the first three years (considering the EC proposal accountability technique and the current ethanol yield from miscanthus), then gradually increasing up to 4.47 million tonnes per period by 2018−20 and afterwards staying constant at those levels. Supposing that the additional demand would be concentrated in a single moment, the initial miscanthus price shock due to the supply chain establishment would be of only 15 c€/t, while the further increases in capacity would augment prices by other 4 c€/t.

Italian additional miscanthus demand for bioethanol production would be not relevant on the world scale, on which the supply curve has been designed, therefore the predictions of energy crops future prices can only be calculated through estimations of global energy crop demand. Furthermore, the hypothesis of perfect substitution of all energy crops in the supply curve with miscanthus may be too hazardous. If the global demand for biomass from energy crops increases by the same amount expected by the abovementioned study (LMC International, 2011), that is 278 million toe by 2020, the average energy crop market price would increase from 48 €/t to 78 €/t, always considering miscanthus as the only energy crop. This latter estimation appears to be more reasonable about the order of magnitude of the price increase.

The analysis of the production costs and their expected trend starts from the breakdown of those costs: this has been possible by elaborating data from expert sources on the topic, like VenetoAgricoltura (2010). It shall be remembered that miscanthus is a perennial crop that requires very little maintenance and has high growing rates (about 3 m per year) even after 15 years that the rhizome has been planted (Scurlock, 1999).

Production costs can be split as reported in table 4.1.

Table 4. 1. *Breakdown of yearly production costs for miscanthus.*

	Share of yearly production costs
Initial capital expenditures	40%
Yearly direct expenses	50%
Final crop expenditures	10%

Initial capital expenditures take into account the rhizomes, land preparation, weeding and fertilization. Once the crop has been planted, this share of the yearly production costs will not increase. For what it concerns yearly expenses, they are composed by fertilization (13%), harvest (26%) and transport inside the farm (61%).

The main components of these cost items are manpower and oil−derived products (chemicals for fertilizers and fuel for agricultural machines) in addition to capital costs for machines. Since it is difficult to estimate the exact contribution of each component to yearly expenses, it can be supposed that the yearly expenses will increase at the same rate as the inflation rate. The final crop expenditures account for the residual 10% of the miscanthus production costs, and they are mainly due to the restoration of the land to its initial state for future crops by using herbicides, plowing land up and all the rest. Since these costs are dealt with once and they are already projected in the future at the moment of establishing the crop, this amount shall not be increased for future estimations. Globally, this method forecasts a slight increase of miscanthus price by half the inflation rate each year, therefore, prices are expected to be at about 57 €/t in 2020 and 60 €/t in 2024 if 2013 price is 50 €/t.

When aggregating the figures obtained by the previous methods, it is encouraging to notice the good fit of the forecasts calculated through the breakdown of production costs with the first literature source, while the other two techniques report very distant values. Furthermore, the Terravesta source and the "energy crops supply curve" approach are less reliable than the other two techniques because of the already mentioned reasons.

Finally, it can be assumed that current miscanthus price that has to be paid to farmers is 50 €/t and it will rise to 60 €/t in 2020. The yearly increase would then be 2.6% per year, which seems to be reasonable. The forecasted prices are resumed in table 4.2:

Table 4. 2. *Forecasted miscanthus prices*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Miscanthus average price (€/t)	50.50	54.10	58.50	63.20	68.40

Corn stover price has been also been studied. A vast research has been conducted specifically for corn stover and also for similar agricultural residues. It can be assessed that corn stover can be purchased in Northern Italy at 35 €/t, as confirmed by a corn stover and straw producer (Euroforaggi, 2012) and by the Chamber of Commerce of Forlì that lists corn straw and whose quotation was between 35 €/t and 40 €/t at the beginning of January 2013 (Camera di Commercio di Forlì-Cesena, 2013). Similar prices are reported in the U.S.A. (McMillan, 2004), while the American Department of Energy also forecasted corn stover supply curve trend until 2030 (Perlack, 2011) and this is reported in figure 4.3.

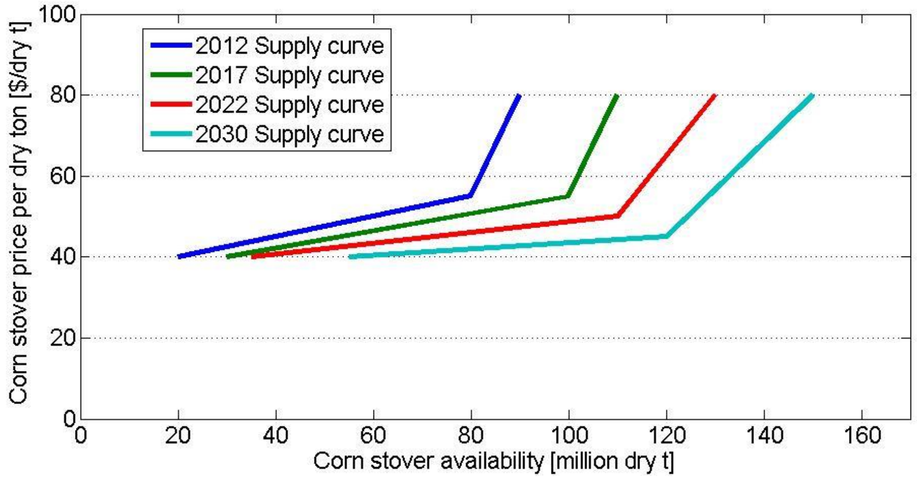

Figure 4. 2. *Trend of the corn stover supply curve until 2030 in the U.S.A. (adapted from Perlack, 2011).*

This shows that corn stover will be increasingly available and at a lower price, for example by 2030 three times as much as the current supply will be available for 40 $/ dry t, that are about 32 €/ dry t or 26 €/t (at average moisture content of 15%). This price is also confirmed by a study about the "stover sustainable harvest rate" (Sesmero, 2011) that set this value at 30% of available corn. This study affirms that no stover is harvested if price is below 43 $/ dry ton, and an increase in harvest rate would require nutrients replacement through fertilizers: for instance it is estimated that if 50% of stover is harvested, additional fertilizers would cost about 23 €/t of stover harvested.

These data are tuned on the American demand and supply levels: the figures shall be converted to the Italian situation. In order to do that, the American minimum stover quantity (20 million dry tonnes) was compared with the total corn production in that country, and this ratio is used to scale down the values to the Italian context by using the Italian corn production. The relative minimum price was set to 30 €/t, an average between the American corresponding price and the quotation of Italian straw. According to this, the minimum stover production in Italy would be 0.65 million dry tons, and the slope change in the supply curve, indicating a feasible stover supply, would be set at 2.60 million dry tons, for which the corresponding price would be 45 €/t. The maximum additional corn stover demand for bioethanol in Northern Italy would be 2 million tonnes (i.e. about 1.7 million dry tonnes): this quantity would not exceed the overall available supply (1.95 million dry tons), therefore the supply/demand match would be feasible. Furthermore, the margin between available supply and demand would increase during the supply chain lifetime, as indicated by the increasing slope change quantity. It has to be noticed that American data forecast an increased availability of corn stover at lower prices (i.e. additional 10 million dry tons would be available at minimum price by 2017). In conclusion, the establishment of a considerable additional stover demand from the beginning of the supply chain lifetime would make current stover price increase by about 10 €/t, but the increasing availability would make Italian corn stover price lower in the future: it can be reasonable to set it at 40 €/t in the two initial periods and then to constant at 35 €/t until 2026.

4.3 Supply chain configuration under EC proposal demand scenario

4.3.1 Supply Chain layout at current cost levels

Supply chain layout under the EC proposal rules has been obtained through modeling in GAMS ® by adding the constraints and the accountability techniques by raw material as illustrated in § 4.1.2. Ethanol price and corn price have been supposed to follow a periodical with trend component model (§ 2.5) but similar results are obtained with other price forecast techniques, while miscanthus and corn stover are the ones reported in § 4.1.3. Capital investments and operative costs for miscanthus and stover−based technologies have been taken from previous works from Giarola (Giarola, Zamboni and Bezzo, 2011; Giarola, Bezzo and Shah, 2011b).

The EC proposal has a strong influence on the profitability of the supply chain, since the losses are reduced by 60% compared with the current configuration, in fact NPV keeps to be negative but for 231 M€, compared with the 552 M€ obtained in the current configuration. Miscanthus−based technology is preferred, of which one plant keeps operating for all the supply chain lifetime producing up to 350 kt of ethanol per year, while it is also used a DGP plant from the third period (2018−2020). Because of this, ethanol produced until 2017 is half the quantity that would have been produced without the EC proposal (since miscanthus−based ethanol accounts as twice for the new accountability technique), than this share increases to 64% by the last period because of the corn−ethanol quota. In the last period, corn ethanol accounts for 43% of really produced ethanol (but only 27.5% of the accounted one). The spatial explicit layout is presented in figure 4.4.

It can be seen that many features are common with the configurations seen in §3.2.2. For instance, plants are located in Eastern Italy, with the miscanthus−based plant close to Venice and the corn−based one close to Udine, while crops are in the neighbor regions and around PortoViro− Ravenna.

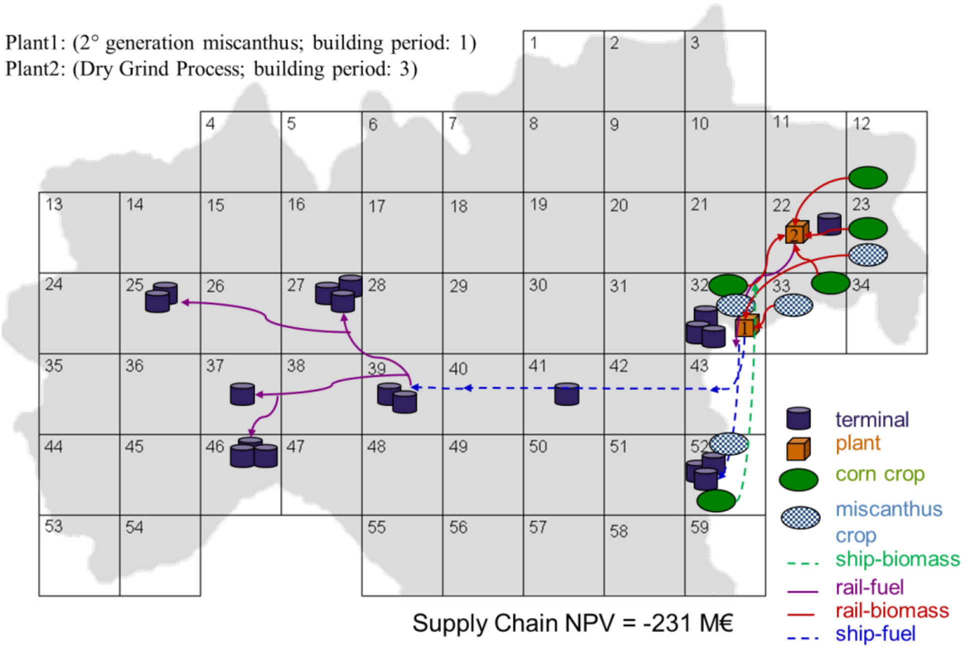

Figure 4. 3. *Economically optimal supply chain layout under EC proposal*

Stover−based supply chain reports a 29% worse NPV (−294 M€) but it requires that only one plant is built, thanks to the EC proposal accountability technique; therefore only one fourth of the ethanol expected without the EC proposal is produced. The SC layout is presented in figure 4.5. As expected, the only plant is located closer to the western Italy demand centers, while it is provided with biomass coming mainly from eastern Italy, that is the most corn producing area.

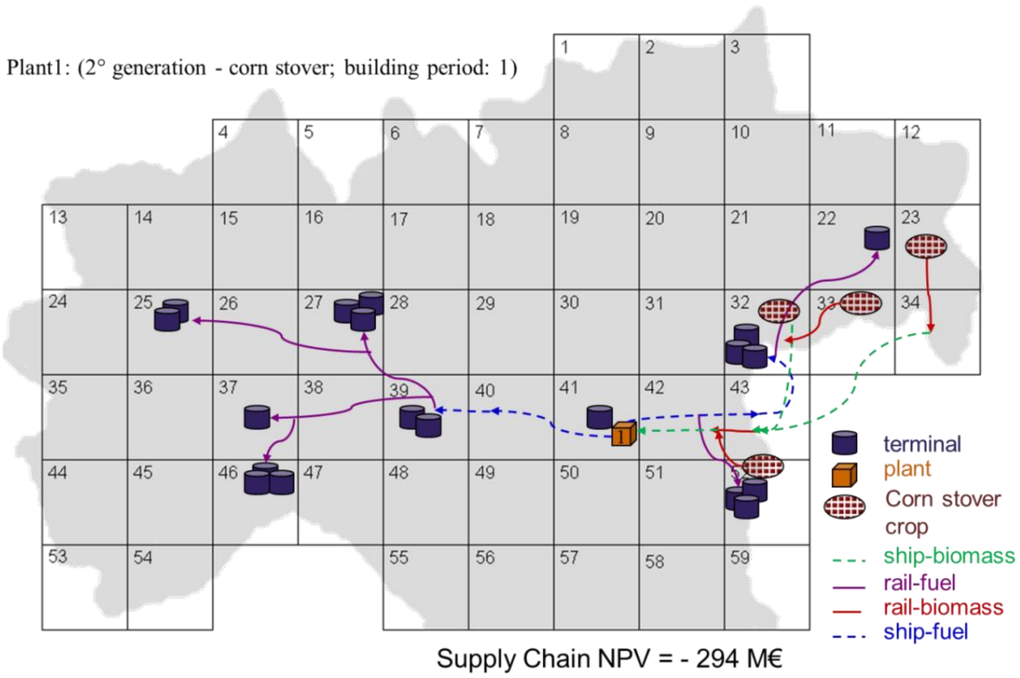

Figure 4. 4. *Corn stover−based supply chain layout under EC proposal*

The EC proposal seems an adequate tool for boosting second generation ethanol production, but still the supply chain would not make profits nor repay completely its expenses. Technological improvements for second generation ethanol are expected, therefore it has been considered an interesting insight to evaluate the CapEx and OpEx reductions that would be necessary for the supply chain to operate economically (§ 4.2.2.1). Other cost reductions can come from the fact that second generation feedstock are grown by the same company that operates the plant, as done by Mossi&Ghisolfi at the pilot plant of BioCrescentino: the impact of this business model is analyzed in § 4.2.2.2. If the supply chain operates at the current cost levels the losses will have to be repaid by governmental subsidies or by customers: this impact is quantified in §4.2.3.

4.3.2 . Required cost reductions for 2nd generation technologies

Since the miscanthus−based supply chain shows better economic performances compared with the configurations without the EC proposal, it has been quantified the required CapEx reduction on the miscanthus−based plants and the combined CapEx and OpEx reduction to make the supply chain profitable. Two studies were conducted on corn stover−based plants to calculate the reductions that would make this raw material preferred over miscanthus and the ones that would make this technology profitable.

Eventually the business model with an vertically integrated company has been studied, and a similar analysis has been conducted to quantify the needed CapEx and OpEx reductions for a profitable supply chain under this condition.

4.3.2.1 CapEx and OpEx reduction

Capital costs are generally the major burden for second generation technologies to impose themselves, and this is demonstrated by the fact that a reduction in CapEx would have a more significant impact than its equivalent reduction in OpEx. Notably, any reduction of the Operative Expenses alone would make the miscanthus−based supply chain profitable, while a reduction by 40% of Capex alone is sufficient to achieve this goal. A combined reduction of both OpEx and Capex by 32% each would obtain the same result.

Stover−based technology would perform as the miscanthus−based one under an economic point of view if its CapEx would be reduced by 13% or its OpEx and Capex would be reduced by 10% at the same time. This decrease appears to be more realistic than the previous ones. Still, the stover−based supply chain would not be profitable: NPV would be positive if CapEx are reduced by at least 57% or Opex and Capex would be reduced by 43% at the same time. The required cost reductions are resumed in table 4.3.

Table 4. 3. *Required CapEx and OpEx reductions for different goals for the second generation technologies.*

Goal	Cost item to be reduced	Required cost reduction
Miscanthus–based supply chain becomes profitable	CapEx only	40%
	CapEx and OpEx jointly	32%
Stover–based supply chain has same economic performance of the miscanthus–based one	CapEx only	13%
	CapEx and OpEx jointly	10%
Stover–based supply chain becomes profitable	CapEx only	57%
	CapEx and OpEx jointly	43%

The calculated reductions have been compared with the technological learning curve of second generation bioethanol production plants, defined as the production cost decreasing path that has been recorded following an increase in technological maturity (Hettinga et al., 2009). The historical curve recorded significant progresses during last years, but a cost reduction of the orders of magnitude that are reported above seems very difficult to be reached. In fact, historically, cost reductions were calculated by 4% every doubling in cumulative ethanol production from second generation technologies. Therefore, the miscanthus–based supply chain and the stover–based supply chain are expected to maintain their negative economic profile, but still more appealing than 1st generation technologies thanks to the EC proposal.

4.3.2.2 Vertically integrated business model

As it has been seen in §4.1.3, miscanthus crop presents high capital costs, as high as almost 5000 €/ha (VenetoAgricoltura, 2010), that is 40% more than poplar for instance. Furthermore it can be harvested during 15 years with a constant growing rate, that is the same duration of the bioethanol supply chain under analysis. Therefore it is worthy suggesting that miscanthus crop shall be managed by the same company that would produce bioethanol. This business model would provide many advantages:

4.1 A reliable supply of feedstock would be guaranteed, without waiting for the market dynamics to respond to the miscanthus additional demand by the company itself;

4.2 Easier and cheaper credit for the initial investment can be accessed compared with the case of single farmers;

4.3 More important, cheaper feedstock would be available, since a smaller margin would be added to production costs, that is miscanthus would be supplied to the bioethanol plant at cost price.

Table 4.4 resumes the forecasted miscanthus prices if the crops were managed by a vertically–integrated company. savings would be of about 20%.

Table 4. 4. *Forecasted miscanthus prices for a vertically–integrated company*

	2012–2014	2015–2017	2018–2020	2021–2023	2024–2026
Miscanthus average price (€/t)	40.40	43.30	46.80	50.60	54.70

This business model is currently used in industrial practice: in fact it has been recently adopted for the second generation bioethanol plant by Mossi&Ghisolfi BioCrescentino near Turin. In that case common cane (Arundo Donax) is used as raw material, which has many features similar to miscanthus, for instance the lifetime of about 12 years and the even higher investment costs, which reach 8000 €/ha (VenetoAgricoltura, 2010).

The vertically–integrated company wouldn't have to face dramatic changes in the supply chain layout, as it can be seen from the simulation results under these hypothesis that are represented in figure 4.6. The corn–based plant would be located close to PortoViro, but the miscanthus plant and the crops stay unchanged. The main change is due to the increased economical profitability of the supply chain, that reduces its losses by 25% compared with a non vertically–integrated business (NPV = −175 M€).

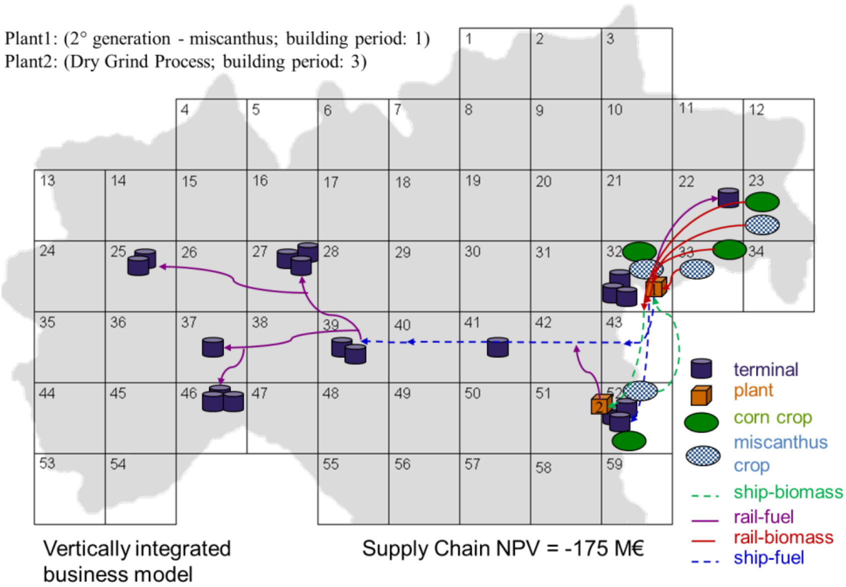

Figure 4. 5. *Supply chain layout for a vertically-integrated company.*

If a slight reduction in CapEx is achieved (~15%), the corn−based plant would be less economic than a second miscanthus−based plant, thus increasing the overall environmental performance of the supply chain, in accordance with the EC Proposal principles.

Furthermore, the required cost reductions to achieve supply chain profitability would be reduced: in fact a 30% CapEx reduction would be sufficient to have a profitable miscanthus−based supply chain, while the same is obtained if a joint OpEx and CapEx reduction by 23% is reached. This appears to be more encouraging than the case with a non−integrated business, but still the cost decrease appears to be unrealistic in the short term.

4.4 Impact of the EC proposal on governmental subsidies and on fuel consumers

The impact of the EC proposal on the final fuel price for customers and the governmental subsides that have to be granted is here presented. Those figures are also compared with the current demand scenario, to which the EC proposal still does not apply. Finally a consideration of the drawbacks of the EC proposal for the customers will be highlighted.

The lower losses of the supply chain under the EC proposal are obtained thanks to the positive cash flows that the supply chain generates from the second period, thus any subvention will be required apart from a consistent help for the plant establishment. In fact losses in the first periods account for 419 M€, that is more than twice the losses that are registered in the same period without the EC proposal, thus confirming once again the CapEx problem of second generation plants. On the other hand, global governmental expenditures would be reduced by more than 70% in current euros compared with the case without the EC proposal. The comparison has been made using a discount rate equivalent to the 15−year term Italian bond rate at beginning of January 2013 (4.70%) because governmental subsidies that would have to be granted would be indexed to that rate. The comparison is resumed in table 4.5.

Table 4. 5. *Bioethanol supply chain losses per period and equivalent in current terms*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026	Total equivalent in current terms[1] (M€)
Supply chain losses with the EC proposal (M€)	418	0	0	0	0	418
Supply chain losses without the EC proposal (M€)	198	25	303	518	871	1294

1: Discounted at the 15 years Italian bond rate

While the supply chain turns out to be less economically disadvantageous than in the demand scenario defined by the current directive, it has to be noticed that less ethanol is produced and therefore the final fuel is made up by a higher share of gasoline.

It can be supposed that final fuel price is obtained as described in § 3.3.3, that is the sum of:

(i) Gasoline price plus taxes weighted on the volume fraction of gasoline;

(ii) Ethanol price plus VAT (21% in Italy) and the per−liter subsidy to the Supply Chain weighted on the volume fraction of ethanol.

In that case the fact that the fuel is made up by a higher share of gasoline allows the final fuel price not to vary much along the years, given that gasoline price stays constant, while the fact that any subside shall be included in the fuel price from the second period onwards make the final fuel cheaper than in the current demand case since the fourth period. When the fuel price at equivalent mileage is taken into account, the EC proposal makes the new blended fuel even more economical compared to the one obtained with the existing directive: that is due to the fact that blended fuel LHV is increased and therefore savings reach almost 3% compared with the current demand scenario. The detailed comparison is shown in table 4.6.

Table 4. 6. *Expected total fuel prices and fuel prices at equivalent mileage in the case with or without EC proposal. Note: Gasoline price considered constant at 1.70 €/l.*

	2012−2014	**2015−2017**	**2018−2020**	**2021−2023**	**2024−2026**
Total fuel price with the EC proposal (€/l)	1.69	1.67	1.67	1.68	1.69
Total fuel price without the EC proposal (€/l)	1.65	1.64	1.66	1.68	1.71
Total fuel price difference	+2.5%	+1.8%	+0.6%	−0.3%	−1.5%
Total fuel price at equivalent mileage with the EC proposal (€/l)	1.71	170	1.71	1.72	1.74
Total fuel price at equivalent mileage without the EC proposal (€/l)	1.69	1.69	1.72	1.75	1.79
Total fuel price at equivalent mileage difference	+1.2%	+0.3%	−0.8%	−1.8%	−2.9%

While this blended fuel seems to have beneficial features for the final consumers, it presents a serious drawback that questions the scope of biofuels itself.

In fact, a higher share of gasoline in the blended fuel means an higher sensitivity to gasoline price fluctuations, thus mitigating the energy security effect of biofuels. In fact, if gasoline price increases suddenly by, say, 10% during the first period, the price of the blended fuel according to the EC proposal will increase by 9,44%. The difference with the current demand case increases as the part of bioethanol in gasoline increases, being almost 1.5% in the last period. Although the price sensitivity, meant as the relative price increase of the fuel when an increase in a reference good, that is gasoline, occurs, tends to diminish as the ethanol part increases, it is always very high and it is always higher than in the case without EC proposal. Table 4.7 reports the blended fuel price relative sensitivity to an increase in gasoline price in each period and the same value is compared in the case without the EC proposal.

Table 4. 7. *Blended fuel price relative sensitivity to gasoline price shocks in different periods. Note gasoline price considered constant at 1.70 €/l.*

	2012−2014	**2015−2017**	**2018−2020**	**2021−2023**	**2024−2026**
Part of a gasoline price relative increase taken by the fuel with EC proposal	94.4%	93.8%	91.5%	89.1%	86.6%
Part of a gasoline price relative increase taken by the fuel without EC proposal	94.5%	93.3%	90.8%	88.2%	85.4%
Sensitivity difference	−0.1%	+0.5%	+0.8%	+1.0%	+1.4%

Also in this demand scenario it was studied the impact of an increasing gasoline price instead of a constant one, as it was done in § 3.3.3. The same forecasted values for gasoline price as in that scenario were used (see table 3.9). Since the impact of the gasoline price dynamics is equivalent in the two demand scenarios, no big difference is recorded. Generally, since gasoline price weights more in the blended fuel according to the demand scenario regulated by the EC proposal, prices tend to grow more in this scenario. The complete comparison is drawn in table 4.8. The price differences with the constant gasoline price case reported in table 4.6 are from +0.1% to +0.9 %.

Table 4. 8. *Expected total fuel prices and fuel prices at equivalent mileage in the case with or without EC proposal. Note: gasoline price evolving as predicted in table 3.9.*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Total fuel price with the EC proposal (€/l)	1.76	1.81	1.90	1.94	1.95
Total fuel price without the EC proposal (€/l)	1.71	1.78	1.88	1.93	1.96
Total fuel price difference	+2.6%	+2.1%	+1.2%	+0.5%	−0.6%
Total fuel price at equivalent mileage with the EC proposal (€/l)	1.78	1.85	1.94	1.99	2.01
Total fuel price at equivalent mileage without the EC proposal (€/l)	1.76	1.83	1.95	2.01	2.05
Total fuel price at equivalent mileage difference	+1.3%	+0.6%	−0.2%	−1.0%	−2.0%

What surprises most is the fact that if gasoline price increases as expected, the blended fuel sensitivity to gasoline price shocks is approximately the same in the two demand scenarios; therefore, in that case, the European Commission proposal would not worsen the energy security contribution of biofuels, as it can be seen from table 4.9.

Table 4. 9. *Blended fuel price relative sensitivity to gasoline price shocks in different periods. Note: gasoline price evolving as predicted in table 3.9..*

	2012−2014	2015−2017	2018−2020	2021−2023	2024−2026
Part of a gasoline price relative increase taken by the fuel with EC proposal	94.5%	94.0%	92.0%	89.9%	87.6%
Part of a gasoline price relative increase taken by the fuel without EC proposal	94.7%	93.8%	91.8%	89.7%	87.2%
Sensitivity difference	−0.2%	+0.3%	+0.2%	+0.3%	+0.4%

Once again, consumers would be burdened with more expensive fuel and it is not sure if the final sustainability of the blended fuel is actually increased: in fact, more sustainable biofuels (i.e. second generation ones) are added but in a minor quantity compared with the current demand scenario.

4.5 Final remarks

The European Commission proposal to modify the existing Directive that regulates biofuel production can be a powerful tool to promote the use of advanced technologies to produce bioethanol (as shown in § 4.2) but also a key to improve the economic performance of the supply chain. Miscanthus–based technology is to be preferred over corn stover one and this can stimulate the diffusion of this energy crop, together with pushing down the production costs of second generation plants.

Globally, consumers will not benefit of the introduction of this proposal except on the long term, and the energy security performance of the blended fuel obtained according to this proposal is not better than the current one. Finally, it still shall be verified if the final sustainability of the fuel is actually increased with this proposal or not, because more sustainable biofuels are added but in a minor quantity compared with the current demand scenario.

Conclusions

This master's degree thesis work is focused on the problem of strategic supply chain design for bioethanol production in northern Italy. Attention was given to the economic performance of the supply chain layout. A Mixed Integer Linear Programming was developed to predict the spatial explicit features of the supply chain while maximizing its economic performance.

Four models to predict the prices of the commodities involved in bioethanol production were implemented. These models were applied directly to forecast corn and ethanol prices along the supply chain lifetime, while other relations were defined to predict the prices of second−generation−technology raw materials, such as corn stover and miscanthus, and of by−products of ethanol production processes, such as DDGS and electricity. Six different technologies involving corn as raw materials were included in the simulation model, four of them recurring to a stillage fermentation module to produce electricity.

The optimal bioethanol supply chain layout was calculated under the four prediction models in order to assess the supply chain robustness to changes in price evolution dynamics. The results of the simulations proved that minimal differences in the optimal supply chain design occur if prices follow different evolution paths, therefore part of the investment risk is mitigated: in fact investors can be confident on the fact that the chosen supply chain is optimal also if commodity prices behave differently.

In all the scenarios the bioethanol supply chain is predicted not to be profitable, and this has been compared with the historical profitability of the American corn−based ethanol supply chain, that shows that without subsides the economic performance would have been seriously compromised. Therefore the impact of the supply chain losses on taxpayers, in the case that the losses would be repaid by governmental subsidies, was assessed. On the other hand, if the losses were to be included in the final fuel price, the future blended price was calculated and the impact on consumers was assessed.

A whole chapter was dedicated to the analysis of the impacts on the optimal bioethanol supply chain design of the recent European Commission proposal to amend part of the existing directive that regulates the biofuel blending requirements. First, the proposal was presented and discussed, then the original MILP model was modified to include the new accountability technique and two second−generation technologies (one based on an energy crop, the other on agricultural residues). This proposal gives more room to second generation technologies in the supply chain design, but the profitability was proved to be still far from being achieved. Cost reductions for second generation technologies were discussed in order to reach an economic breakeven for both types of technologies under the proposed demand scenario.

Furthermore, the impact of this proposal on taxpayers and on fuel consumers was compared with the current directive scenario, in order to evaluate the positive aspects and the drawbacks of the proposed modifications to the existing directive.

While this work provides a complete overview of the economic performance of the bioethanol supply chain layout and assesses its impact on fuel consumers under different price evolution dynamics and different bioethanol demand scenarios, still there is room to extend this study.

Notably, three axis for enlarge the scope of this work are perceived. The first one would be to update the economic hypothesis of the model, notably for second−generation technologies, and also ethanol blending rates by comparing them with the real biofuel blending in Italy in the last years. Furthermore, it would be important to extend the scope of the MILP models both on the geographic point of view and on the application (that is extended to the design of biodiesel supply chain, which accounts for most of the Italian biofuels) in order to have a comprehensive tool for the strategic planning of the biofuels production in the whole Italy. Then, the MILP model taking into account the demand scenario proposed by the European Commission could be used to assess the environmental and sustainability improvements taken by this proposal, in order to have a complete understanding of the impact of this proposed reform.

Hopefully, this work can also become a basis for collaboration between the CAPE laboratory, which matured a deep knowledge on the bioethanol supply chain design models, and industrial companies focused on this business.

Appendix

Changes to the supply chain model

Three main changes were introduced in the Giarola model (2011) which was used as a base for the mathematical formulation of the supply chain design:

(i) The expression of the plant size−determining variable λ;

(ii) The introduction of time evolving commodity prices;

(iii) The formulation of the stillage demand, which is dependent on other commodities.

The problem with the plant size determining variable is that Giarola model defined it as in equation A.1 :

$$\lambda_{p,k,g,t}=\lambda_{p,k,g,t-1}+\lambda^{plan}_{p,k,g,t}\ , \qquad \forall k,g,p,t \tag{A. 1}$$

where $\lambda^{plan}_{p,k,g,t}$ is the variable linked to the building of a new plant: therefore unless a new plant is built, the value of $\lambda_{p,k,g,t}$ could not change. That limits the possibility of the plant to increase or decrease its production capacity.

It was modified as expressed in equation (1.20), that is by adding a variable that allows to take into account plant size changes:

$$\lambda_{p,k,g,t}=\lambda_{p,k,g,t-1}+\lambda^{plan}_{p,k,g,t}+\lambda^{grow}_{p,k,g,t}\ , \qquad \forall k,g,p,t \tag{1. 20}$$

With $\lambda^{grow}_{p,k,g,t}$ that can range from −1 to +1. Plant size reductions are also allowed, but it is less likely to happen because ethanol demand is increasing during the analyzed periods.

The main impact of this new formulation is on the total capital investment, that shall take into account also enlargements: the original formulation (eq A.2) is replaced by the one reported in chapeter 1 (1.17)

$$TCI_t=\sum_{p,k,g} CI_{p,k}\cdot\lambda^{plan}_{p,k,g,t}\ , \qquad \forall t \tag{A. 2}$$

$$TCI_t=\sum_{p,k,g} CI_{p,k}\cdot\lambda^{plan}_{p,k,g,t}+Enl_{k,g,t}\ , \qquad \forall t \tag{1. 17}$$

With the variable $Enl_{k,g,t}$ defined as in equation (1.18)

$$Enl_{k,g,t}=\sum_{p}\lambda_{p,k,g,t}^{grow}\cdot CI_{p,k} \quad , \qquad \forall t \tag{1. 18}$$

Plant enlargement costs are constrained to be positive since it is supposed that no profit is made when the plant reduces its capacity: in fact it would simply work under its maximal building capacity. A problem occurs if an enlargement follows a capacity reduction, because in that case the enlargement is taken into account even if the plant would have the theoretical capacity to produce at the new required output. Several attempts were made to take into memory the maximum plant capacity and to calculate enlargements only with regards to this, but no linear technique was proved to be successful at this.
Many variable are indirectly affected by this modification, as depreciation (which depends on total capital investment) and ethanol production rate, among others.
In the original Giarola model, commodity prices were fixed for all the periods. A modification was introduced when the stochastic approach was introduced (Giarola et al, 2011b) but the current model considers the market prices of all raw materials and all sold goods as a three−dimensional matrix, dependent on the commodity itself, on the time period and on the geographic location in which it is traded. That allows to take into account the effect of commodity price differences between autochthon and foreign production of biomass (which is discussed in § 3.1.4) and to steer operational decisions. Furthermore, the iso−dimensionality of the matrices allows to easily cross−link commodity prices, as it was done with DDGS market price which was set to be as corn price times a proportional term (as explained in §3.1.3).
A particular raw material was stillage, which shall be added to certain first generation bioethanol production technologies (as briefly discusses in §1.2.1). In fact stillage demand is dependent on the technology used and on the ethanol production with this technology. Furthermore, the wide availability of this good does not require any complicate logistic design and the local transport cost within the region in which the plant was built was accounted in the commodity price.
Stillage demand was decomposed in two parts: a component derived from the demand of stillage linked to corn treatment process (common to all biogas technologies) and an additional stillage requirement which is positive only for the technology that require excess stillage instead of natural gas. The first part is obtained by multiplying the ethanol demand in each plant by a term which is zero for technologies not using biogas. Since the proportional term was available with respect to corn demand, the ethanol production was simply divided by the corn to ethanol yield, as expressed in equation (A. 3)

$$Stillage_{TOT}=Stillage_{EXCESS}+\sum_{k,g}\frac{P_{ethanol,\,k,\,g,t}\cdot StillageYield(k)}{\gamma} \tag{A. 3}$$

The additional stillage demand ($Stillage_{EXCESS}$) was expressed through a proportional term dependent on the technology and on the plant size and by using the plant size determining variable, as in equation (A.4)

$$Stillage_{EXCESS} = \sum_{p,k,g} \frac{ER(p) \cdot \lambda_{p,k,g,t} \cdot StillageYield(k) \cdot StillageExcess(p,k)}{\gamma} \qquad \text{(A. 4)}$$

The stillage purchase cost was finally included in the biomass purchase cost by multiplying the variable $Stillage_{TOT}$ by the stillage purchase cost, that was supposed to be 25 €/t including the transport costs to the plant.

References

Abbassian , A. (2006) *Maize International Market Profile*, FAO.
Almansoori, A. and Shah, N. (2006) 'Design and operation of a future hydrogen supply chain. Snapshot model', *Chemical Engineering Research and Design*, vol. 84, pp. 423-438.
Associazione Granaria di Milano (2012) *Borsa dei Cereali*, [Online], Available: http://borsa.granariamilano.org/visualizza_listino.php3.
ASSOSEMENTI (2012) *Import export sementi in Italia 2009-2011*, [Online], Available: http://www.sementi.it/statistiche/217/import-export-sementi-italia-2009-2011 [25 Oct 2012].
Berk, J. and De Marzo, P. (2008) *Corporate Finance*, Old Tappan, NJ: Person Education.
Bernardi, A., Giarola, S. and Bezzo, F. (2012) 'Spatially explicit multi-objective optimisation for the stategic design of first and second generation biorefineries including carbon and water footprints', *Industrial and Engineerign Chemistry Research*.
BEST, (BioEthanol for SustainableTransport) (2009) *WP5-report: Incentives to promote Bioethanol in Europe and abroad*.
Biomass Trade Centers (2009) *Colture energetiche per i terreni agricoli*, [Online], Available: http://nuke.biomasstradecentres.eu/Portals/0/D2.2.1%20SRC%20practical%20booklet_AIEL_%20IT.pdf [7 Jan 2013].
BioPact (2007) *Report: US ethanol sector does not need subsides*, [Online], Available: http://news.mongabay.com/bioenergy/2007/09/report-us-ethanol-sector-does-not-need.html [9 Nov 2012].
Bloomberg (2013) *China's Power Consumption Slows in 2012 as Economic Growth Eases*, 14 Jan, [Online], Available: http://www.bloomberg.com/news/2013-01-14/china-s-power-consumption-slows-in-2012-as-economic-growth-eases.html [21 Jan 2013].
Camera di Commercio di Forlì-Cesena (2013) *Listino prezzi paglia di mais*, [Online], Available: http://www.fc.camcom.it/prezzi/listino/prodotti/prodotto.jsp?id=1343 [8 Jan 2013].
Chandel, A.K., Es, C., Rudravaram, R., Narasu, L., Rao, V. and Ravindra, P. (2007) 'Economics and environmental impact of bioethanol production technologies: an appraisal', *Biotechnology and Molecular Biology Review*, vol. 2, no. 1, pp. 14-32.
Chen, Kuo and Chen (2010) 'Modeling the relationship between oil price and global food price', *Applied Energy*, pp. 2517-2525.
CIA (2011) *The World Factbook - Inflation rates*, [Online], Available: https://www.cia.gov/library/publications/the-world-factbook/fields/2092.html [25 Oct 2012].
Cmegroup (2012) *CBOT Denatured Fuel Ethanol Futures*, 23 Oct, [Online], Available: http://www.cmegroup.com/trading/energy/ethanol/cbot-ethanol.html.

Cmegroup (2012) *Corn Futures*, 23 Oct, [Online], Available: http://www.cmegroup.com/trading/agricultural/grain-and-oilseed/corn.html.

Congressional Research Service (2011) *U.S. Oil Imports: Context and Consideration - CRS Report for Congress*, Washington: CRS.

Dal Mas, M., Giarola, S., Zamboni, A. and Bezzo, F. (2011) 'Strategic design and investment capacity planning of the ethanol supply chain under price uncertainty', *Biomass and bioenergy*, vol. 35, pp. 2059-2071.

Douglas, J.M. (1988) *Conceptual design of chemical processes*, New York: McGraw-Hill.

Du, X. and Hayes, D. (2008) *The Impact of Ethanol Production on U.S. and Regional Gasoline Prices and on the Profitability of the U.S. Oil Refinery Industry*, Ames, Iowa: Center for Agricultural and Rural Development - Iowa State University.

EIA (2012) *Annual Energy Review*.

eLeMeNS (2012) *Rinnovabili elettriche, analisi del DM 6 luglio 2012*, [Online], Available: http://www.lmns.it/wp-content/uploads/2012/07/casaclima.com-13_07_20121.pdf [26 Sep 2012].

Euroforaggi (2012) *Pellet di paglia e stocchi di mais presso Bagioni group*, [Online], Available: http://www.mixbiopells.eu/fileadmin/user_upload/WP3/Best_practices_transl/Italian/Best_practice_pelletising_CTI_IT.pdf [7 Jan 2013].

European Commission (17/10/2012) *Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70 and 2009/28*, Brussels.

European Commission Eurostat (2006) *Transport energy consumption and emissions*, [Online], Available: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Transport_energy_consumption_and_emissions.

FAO, OECD (2011) *Agricultural Outlook 2011-2020*.

FAPRI-ISU (2011) *World Agricultural Outlook*.

Farrell, A., Plevin, R., Turner, B., Jones, A., O'Hare, M. and Kammen, D. (2006) 'Ethanol Can Contribute to Energy and Environmental Goals', *Science*, vol. 311, no. 5760, pp. 506-508.

Ferrazzi, G. (2008) *L'impiego di mais per la produzione di bioetanolo per autotrazione: una valutazione dei potenziali impatti sul sistema agroalimentare mondiale*.

Fini, A., Oliosi, M. and Manca, D. (2011) 'Dynamic Conceptual Design under market uncertinty and price volatility', *Computer Aided Chemical Engineering*, vol. 29, pp. 336-340.

Flake, O. (2012) *Strong Start for 2012 DDG Exports Follows Record Shipments in 2011*, USDA - Foreign Agricultural Service.

Franceschin, G., Zamboni, A., Bezzo, F. and Bertucco, A. (2008) 'Ethanol from corn: a technical and economical assessment based on different scenarios', *Chemical Engineering Research and Design*, vol. 86, pp. 488-498.

Giarola, S., Bezzo, F. and Shah, N. (2011b) 'A risk management approach to the economic and environmental strategic desiggn of ethanol supply chains', *[Unpublished]*.

Giarola, S., Zamboni, A. and Bezzo, F. (2011) 'Spatially explicit multi-objective optimisation for design and planning of hybrid first and second generation biorefineries', *Computers and Chemical Engineering*, p. 1782– 1797.

Governo Italiano (2013) *Sviluppo Economico_Struttura prezzi carburanti*, [Online], Available: http://www.sviluppoeconomico.gov.it/images/stories/prezzi/struttura/Tabella_Prezzi_2013_01_21.pdf.

Häggström (2002) *Finite Markov Chains and Algorithmic Applications*, Cambridge: Cambridge University press.

Hasings, A., Sunnenberg, G., Lovett, A., Finch, J., Wang, S., Hillier, J. and Smith, P. (2011) *Spatial Mapping and evaluation of Miscanthus crop distribution in Great Britain to 2050*, [Online], Available: http://www.carbo-biocrop.ac.uk/uploads/Hastings_miscanthus%20yields_UKERC.pdf [7 Jan 2013].

Heaton, E., Boersma, N., Caveny, J., Voigt, T. and Dohleman, F. (2012) *Miscanthus (Miscanthus x giganteus) for Biofuel Production*, [Online], Available: http://www.extension.org/pages/26625/miscanthus-miscanthus-x-giganteus-for-biofuel-production [7 Jan 2013].

Hettinga, W.G., Junginger, H.M., Dekker, S.C., Hoogwijk, M., McAloon, A.J. and Hicks, K.B. (2009) 'Understanding the reductions in US corn ethanol production costs: An experience curve approach', *Energy Policy*, pp. 190-203.

Hofstrand, D. (2012) *d1-10ethanolprofitability.xls*, [Online], Available: https://www.extension.iastate.edu/agdm/energy/html/d1-10.html [25 Sep 2012].

Hofstrand and Johanns (2012) *Ethanol Plant Prices*, [Online], Available: www.extension.iastate.edu%2Fagdm%2Fenergy%2Fxls%2Fagmrcethanolplantprices.xls&ei=uly3UJX8ApD04QTerYC4BA&usg=AFQjCNGfPTQjSYK6eLwvaMcqA2yDU_QzvQ&sig2=9cji_9 [25 Sep 2012].

Hugo, A. and Pistikopoulos, E. (2005) 'Environmentally conscious long range planning and design of supply chain networks', *Journal of Cleaner Production*, vol. 13, pp. 1471-1491.

ICIS (2012) *ICIS Pricing Ethanol Europe*, [Online], Available: http://www.icispricing.com/il_shared/samples/subpage108.asp.

IEA (2012) *US ethanol production plunges to two-year low*, 13 Aug, [Online], Available: http://www.iea.org/newsroomandevents/news/2012/august/name,30389,en.html [9 Nov 2012].

Kfouri, G. (2011) *EU votes in favor of hiking import taxes for high ethanol blends*, 13 Oct, [Online], Available:
http://www.platts.com/RSSFeedDetailedNews/RSSFeed/Petrochemicals/8457292 [25 Oct 2012].
Kwiatkowski, J., McAloon, A., Taylor, F. and Johnston, D. (2006) 'Modeling the process and costs of fuel ethanol production by the corn dry-grind process', *Industrial Crops and Products*, vol. 23, p. 288–296.
LMC International (2011) *Can energy crops compete with residues and woody biomass?*, Rotterdam.
Luchansky, M.S. and Monks, J. (2009) 'Supply and demand elasticities in the U.S. ethanol fuel market', *Energy Economics*, p. 403–410.
Martin, M., Svensson, N., Fonseca, J. and Eklund, M. (2012) 'Quantifying the environmental performance of integrated bioethanol and biogas production', *Renewable Energy*, pp. 1-8.
Marzoughi, H. and Kennedy, P.L. (2012) 'The Impact of Ethanol Production on the U.S. Gasoline Market', Southern Agricultural Economics Association Annual Meeting, Birmingham.
McMillan, J.D. (2004) *Biotechnological Routes to Biomass Conversion*, Golden, CO: DOE/NASULGC Biomass & Solar Energy Workshops, 2004.
NACS (2012) *Minnesota Ethanol Producers Running on Empty*, 25 Sep, [Online], Available: http://www.nacsonline.com/NACS/News/Daily/Pages/ND0925123.aspx [9 Nov 2012].
Nghiem, N. (2008) 'Biofuel feedstocks', in Drapcho, Nghiem and Walker (ed.) *Biofuels Engineering Process Technology*, McGrawHill.
Panoutsou, C. and Castillo, A. (2011) *Outlook on Market Segments for Biomass Uptake by 2020 in the UK*, Biomass Futures.
Park, H. and Fortenbery, T.R. (2007) 'The Effect of Ethanol Production on the U.S. National Corn Price', NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management, Chicago.
Penazzi, S. (2012) *Ottimizzazione della filiera di produzione di bioetanolo implementando meccanismi economici di "emission trading"*, Padova: Università degli studi di Padova.
Perlack, B. (2011) *2011 Feedstocks Review Supply Forecast & Analysis*, Oak Ridge National Laboratory.
Renewable Fuels Association (2012) *Ethanol facts: Energy Security*, [Online], Available: http://www.ethanolrfa.org/pages/ethanol-facts-energy-security.
Schill, S. (2007) *Miscanthus versus switchgrass*, [Online], Available:
http://www.ethanolproducer.com/articles/3334/miscanthus-versus-switchgrass [7 Jan 2013].
Scurlock, J.M.O. (1999) *Miscanthus: A review of the European experience with a novel energy crop*, Oak Ridge, TN: U.S. DEPARTMENT OF ENERGY.

Sesmero, J.P. (2011) 'Sustainability of Corn Stover Harvest for Biomass', Agricultural & Applied Economics Association AAEA & NAREA Joint Annual Meeting, Pittsburgh.
Sharp, W.F. (1964) 'Capital Asset Prices: A Theory of Market Equilibrium under Conditions of Risk', *Journal of Finance*, vol. 19, pp. 425-442.
Stock, J. and Watson, M. (2003) *Introduction to Econometrics*, London: Pearson Education.
Teagasc-AFBI (2010) *Miscanthus Best Practice Guidelines*.
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.
Tsang, K.H., Samsatli, N.J. and Shah, N. (2007) 'Capacity investment planning for multiple vaccines under uncertainty. 1. Capacity planning.', *Food Bioproduction Process*, vol. 85, pp. 120-128.
Tyner, W. and Taheripour, F. (2008) 'Policy Options for Integrated Energy and Agricultural Markets', Atlanta.
Unione Petrolifera (2012) *Previsioni Unione Petrolifera 2012*, [Online], Available: http://www.unionepetrolifera.it/it/CMS/pubblicazioni/get/2012/Previsioni%20UP%202012_2025.pdf.
US Energy Information Administration (2012) *Biofuels Issues and Trends*.
USDA (2012) *World Agricultural Supply and Demand Estimates*.
USDA ERS (2012) *USDA - Economic Research Service: Corn Trade*, [Online], Available: http://www.ers.usda.gov/topics/crops/corn/trade.aspx#world [25 Oct 2012].
VenetoAgricoltura (2010) *Colture Energetiche per il disinquinamento della laguna di Venezia - progetto BioColt*, [Online].
Wang, M., Han, J., Dunn, J., Cai, H. and Elgowainy, A. (2012) 'Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn,sugarcane and cellulosic biomass for US use', *Envirnmental Research letters*, vol. 7, pp. 1-13.
WP21 (2005) *Miscanthus/Switchgrass Systems*, [Online], Available: http://www.fnu.zmaw.de/fileadmin/fnu-files/projects/enfa/hamburg05/WP_21_Hamburg_May_05.pdf [8 Jan 2013].
Yano, Y., Blandford, D. and Surry, Y. (2010) *The impact of feedstock supply and petroleum price variablity on domestic biofuel and feedstock markets - The case of the United States*, Swedish Departement of Agricultural Sciences.
Zamboni, A., Bezzo, F. and Shah, N. (2009) 'Spatially Explicit Static Model for the Strategic Design of Future Bioethanol Production Systems. 2. Multi-Objective Environmental Optimization.', *Energy Fuels*, vol. 23, pp. 5134-5143.
Zarnowitz, V. and Ozyildirim, A. (2006) 'Time series decomposition and measurement of business cycles, trends and growth cycles', *Journal of Monetary Economics*, vol. 53, p. 1717–1739.

Ringraziamenti

Giunto alla fine di questo percorso di studio, mi pare lecito ringraziare le persone più importanti per il conseguimento di questo traguardo.

Innanzitutto ringrazio i miei genitori e la mia famiglia tutta, così vicini anche quando ero geograficamente lontano, così importanti sia moralmente che economicamente per avermi permesso questi studi.

Ringrazio i miei compagni di studio, che sono anche diventati buoni amici, tra tutti Martina, a cui devo molto di questo titolo, e Natascia.

Una menzione va anche per i miei amici con i quali ho condiviso molte rinunce e molti momenti divertenti, su tutti Niccolò, Gigi, Eduardo, Giacomo e Alberto.

Mi piace ricordare qui anche coloro con cui ho condiviso la stupenda avventura che è stato il mio soggiorno all'École Centrale Paris e che sono stati per me una seconda famiglia, in particolare Giulio, Riccardo, Julien, Juan Pablo, Jérémy, Benji, Emile, Nicolas, Christine, YingTing, Juan, Matheus, Caio, e ce ne sarebbero ancora moltissimi.

Non posso non citare qui chi mi ha dato il suo completo appoggio in questi ultimi quattro anni, fatti di difficoltà e distanze ma anche di gioie e di fiducia, ovvero Giulia.

Nel giorno della mia proclamazione ricorre anche l'anniversario di colui che ha marcato di più la mia infanzia e che voglio ricordare con affetto, ovvero mio nonno Alfonso. Insieme a lui va un pensiero agli altri nonni che non ci sono più, di cui tanto ero orgoglioso e che ora spero di ricambiare. Alla nonna Amalia, invece, va un pensiero speciale, a lei che con grande tenacia e forza d'animo, è ancora qui tra noi e che, con tutte le sue forze, ha sempre voluto assistere a questo momento.

Ringrazio infine tutti quelli che hanno creduto in me in questi anni di studio, ma ancor di più quelli che non l'hanno fatto o che mi hanno sottovalutato e mi hanno messo un bastone tra le ruote, perché è grazie a loro che sono diventato più forte, determinato e maturo.

Un grazie anche al professor Bezzo e al professor Manca per i preziosi consigli durante il periodo di tesi e a tutti i compagni del CAPE−Lab, a partire da Andrea, Ricardo e Matteo.

Infine grazie a tutti quelli che condivideranno con me la gioia di questa festa.