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Biofuel sustainability: review of implications for land use and food price

This article reviews the main findings, obtained from the literature, on two aspects that question first generation biofuel sustainability: the consequences of increased biofuel production on indirect land use change (ILUC) and related emissions and the impact of biodiesel on food-commodities prices.
The measurement of ILUC, although necessary, is currently highly uncertain as demonstrated by the wide variation in estimates; in any case it seems that none of the first generation biofuels will be able to fulfill the sustainability criteria imposed by the RE Directive.
Regarding the food-fuel debate, even if discrepancies in results have been observed, this review suggests that changes in biofuel prices have little impact on food prices. On the other hand, the impact of an increasing production of biofuel on food prices is not negligible.

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1. Introduction

Industrialized countries' dependence on fossil fuels has been distressing for a long time for countries that do not have self-sufficiency, whether for environmental, economic, geopolitical or other reasons. The burning of fossil fuels contributes to greenhouse gas emissions increasing the risk of intensifying climatic disturbances that can deteriorate the processes of production, consumption and welfare in the world (Shikida *et al.*, 2014). Therefore, the development of renewable energy sources (including biofuels) could provide a valid alternative to fossil fuels (Jaeger and Egelkraut, 2011).

Biofuel have become a high priority issue in the European Union as well as in many other Countries around the world, due to concerns regarding oil dependence and an interest in reducing CO_2 emissions. Nowadays, worldwide biofuels markets are dominated by ethanol (79%) and biodiesel (21%) (REN, 2013; Finco, 2012).

However, several authors (De Fraiture, 2008; Campbell and Doswald, 2009; Demirbas, 2009; Diaz- Chavez, 2011; Ajanovic, 2011; Finco *et al.*, 2012; Padella *et al.*, 2012) have recently raised concerns about the environmental benefits and social-economic implications of biofuel production such as underlying

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uncertainties over the life cycle emissions of greenhouse gas emissions (GHG), possible deforestation for feedstock production, degradation of soil and air quality, increased water consumption, possible loss of biodiversity, possible competition with food production, and other potential social imbalances (Gnansounou, 2011).

In order to be sustainable, biofuels should be carbon neutral, especially considering the necessity of fossil fuel substitution and global warming mitigation. In addition, biofuels should contribute to the economic development and equity. Moreover, they should not affect the quality, quantity, and use of natural resources as water and soil, not to affect biodiversity and not have undesirable social consequences (Lora *et al.*, 2011).

Nevertheless, the length and complexity of biofuel supply chains make the sustainability issue very challenging. Biofuel' pathways include several successive segments over the fuels' life cycle (e.g. feedstock production, conversion of the feedstock to biofuels, wholesale trade, retail, and use in engines) and multiple actors (e.g. feedstock suppliers, biofuel producers, biofuel consumers, and public authorities).

Land-use change is considered one of the most important environmental impacts to address, mainly because of its impacts on GHG and wider ecosystems. Careful assessment of these impacts has given rise to criticisms from economists, ecologists, NGOs, and international organizations, who call for additional analysis of biofuels' effects. Furthermore, the European Union and several countries have adopted certification scheme for biofuels to respond to these growing concerns and to address the sustainability issues derived from the expanding production of biofuels.

At the same time, the impact of biofuels on food prices has been fiercely debated principally in the light of the agricultural commodity price spikes in 2007/2008 and again more recently in 2010/2011. This is because most of the feedstocks currently used to produce biofuels, such as oilseeds in Europe, are also important globally traded food commodities.

This work summarizes the main findings of different lines of research on these two aspects that put at risk first generation biofuels sustainability. Two bodies of literature are revised: one on the consequences of increased biofuel production on land use change and another on the impact of biodiesel on food-commodities prices.

2. Impact of biofuel on land use change

Reducing the greenhouse gas emissions of the transport sector, particularly road transport, is one of the major challenges for policy makers when it comes to tackling climate change. With liquid fuels likely to remain the primary energy source for road transport for at least the next few decades, biofuels have been widely accepted for years as one of the potential solutions for lowering the greenhouse gas emissions of transport (Ernst & Young, 2011). In other words, there was general agreement that production and consumption of biofuels could entail emission savings compared to conventional fuels. This is because the crops used to make the fuels absorb carbon dioxide (CO_2) as they grow. The gas is later released when the biofuels are used.

However, using plant carbon is not free because it means the carbon, or the ability of land to support photosynthesis of other plants, cannot be used for other purposes. Sometimes that means a direct loss of carbon sequestration. Sometimes it means the diversion of carbon in crops from serving their typical purposes as food or feed. It is necessary to calculate both direct and indirect land use change to determine if there is in fact a net gain to diverting plants or the land that produces them to biofuels (Edwards *et al.*, 2010).

It is necessary to clarify the difference between direct and indirect land use changes and understand their consequences. They are defined as follows:

- ***Direct Land Use Change:*** when demand for biofuels increases, farmers will have an incentive to meet this demand by producing more feedstock for biofuels production. This increase in production of feed- and foodstock can either be met by increasing the yield (output) of existing cropland (yield intensification), or increasing cropland area by cultivating previously uncultivated land. The higher the carbon stock of the specific vegetation the more carbon will be emitted into the atmosphere from cropland expansion. The release of carbon from expanding cropland for biofuel feedstock production in natural lands (due to burning or microbial decomposition of organic carbon stored in plants and soil) is known as the direct land-use change effect. It is theoretically possible to observe direct land-use change. This is done e.g. by keeping track of the land-use before potential cropland expansion. Since it is possible to observe the effect it is also possible to regulate. For example, in order for a specific biofuel to be sustainable, in the terminology of the EU Renewable Energy Directive, it must not be grown in an area, which used to contain high carbon stock.
- ***Indirect Land Use Change:*** when feedstock used for biofuels is produced on existing cropland there are no direct land use change effects. However, since agriculture production is displaced, the price of the displaced products will increase. Due to the relatively high substitutability between agricultural products the global food price will increase in response to the reduced supply. In turn, the increase in food prices creates an incentive to expand cropland for agricultural production. The release of carbon from

expanding cropland for production of displaced agriculture products, known as the indirect land-use change effect, could negate the carbon benefits associated with biofuel programs and affect the biodiversity, the soil quality, and the natural resources in a certain region (Perimenis *et al.*, 2011; Copenhagen Economics, 2011). In other words, indirect effects are mainly market related effects; changing market prices of different products is the link between biofuel promotion and indirect effects (Delzeit *et al.*, 2011; Zilberman *et al.*, 2010).

These aspects were taken into account for the first time in two studies published in 2008 (Searchinger *et al.*, 2008; Fargione *et al.*, 2008) which affected the good reputation of first generation biofuels. Using economic models they found that large scale biofuel production induced by current policies, in addition to the emissions accounted for in the production of feedstocks up to tailpipe emissions, are also responsible for other adverse impacts linked to changes in the use of land due to feedstock production (Di Lucia *et al.*, 2012). When these LUC emissions are taken into account, the GHG mitigation benefits of biofuels could be eroded or even negated and hence biofuels may create a "carbon debt" with a long payback period (Khanna *et al.*, 2011; Zezza, 2011).

These concerns on the negative consequences of dLUC and especially ILUC on GHG emissions, had impact on policymaking. Within the EU, in 2009 the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD) were introduced with a set of sustainability criteria for biofuels and bioliquids used to achieve the Directive targets (Alhgren *et al.*, 2014). In particular, the RE Directive established that the GHG emission reduction from the use of biofuels compared to the use of fossil fuel shall be at least 35% for current biofuels and at least 50% from 1 January 2017 onwards (Art. 17(2)). From 1 January 2018, the emission reduction shall be at least 60% for biofuels produced in installations in which the production started on or after 1 January 2017. According to the RED, the value of carbon content for fossil fuel to consider in the comparison should be 83.8 gCO_2eq/MJ[1]. If we consider, for example, the current 35% level this means that a biofuel is not allowed to exceed ~54.5 gCO2eq/MJ emission in the whole production process. The EC has only determined standardized default values for direct emission produced during the whole production process (*cultivation*, *processing*, *transport* and *distribution*) which represent a conservative estimate of the actual values. Nevertheless, for the sake of the comparison with fossil fuels, in addition to these emissions, the ones coming from land use change must be taken into account.

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[1] Other studies argue that this value is too low and instead a value of 90.3 gCO_2eq/MJ should be taken into account (Laborde, 2011).

At that time though, the LUC science was in its infancy (Finkbeiner, 2013), so that the RE Directive reports as following:

> The Commission should develop a concrete methodology to minimize greenhouse gas emissions caused by indirect land-use changes. To this end, the Commission should analyze, on the basis of best available scientific evidence, in particular, the inclusion of a factor for indirect land-use changes in the calculation of greenhouse gas emissions and the need to incentivize sustainable biofuels which minimize the impacts of land-use change and improve biofuels sustainability with respect to indirect land-use change.

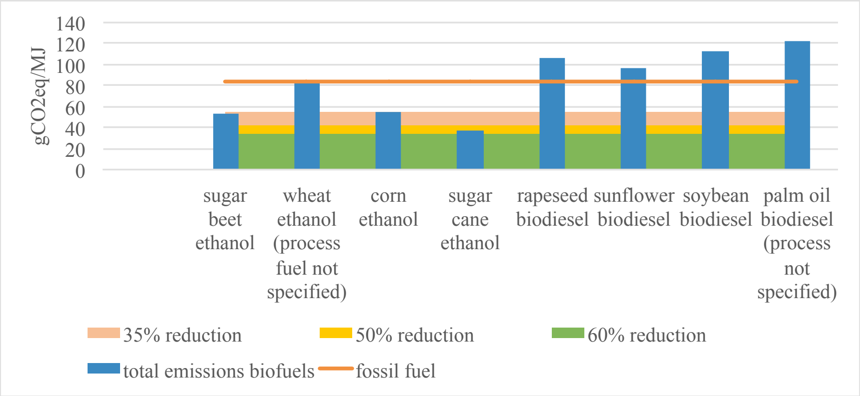
As a result, a large number of studies, using various economic models, were commissioned by the EC itself and other stakeholders, initially to measure the implications in terms of price trends (and their contribution to food crises) and subsequently to investigate the possible range of ILUC "coefficients" (or factors) linked to first generation biofuels production (Dunkelberg *et al.*, 2012; Gohin, 2013). These coefficients are generally stated in grams of CO_2 equivalent per Megajoule of biofuel (gCO_2e/MJ). The EU uses a 20-year period to sum the emissions due to land conversion, and also biofuel production on the converted land. The emissions have to be estimated over an extended period because some emissions are released slowly, while other emissions are released more quickly (Darlington *et al.*, 2013).

In 2012, the Commission released a proposal of Directive (COM 595, 2012) with the aim of improving the reporting of greenhouse gas emissions by obliging Member States and fuel suppliers to report the estimated indirect land-use change emissions of biofuels as a complement to the reduction of the usual life cycle assessment (LCA) of different biofuels pathways (Bernesson *et al.*, 2004; Mortimer and Elsayed, 2006; Hansson *et al.*, 2007; Zah *et al.*, 2007; Halleux *et al.*, 2008; Stephenson *et al.*, 2008; Lechon *et al.*, 2009; Thamsiriroj and Murphy, 2009; Herrmann *et al.*, 2012; Nanaki and Koroneos, 2012; Gonzalez-Garcia *et al.*, 2013; Malca *et al.*, 2014; Rasetti *et al.*, 2014). The Commission introduced ILUC factors relying on the results of a study of land use change emissions completed in 2011 by the International Food Policy Institute (IFPRI) for the Directorate General for Trade of the European Commission.

Therefore, total policy-estimated GHG emissions should be given by the sum of the default values of direct emissions established in the RED and the ILUC factors proposed by the COM 595 (Ahlgren *et al.*, 2014), as shown in Figure 1.

From this Figure we can see that if the proposed values were to be introduced into the EU policy to assess compliance with the minimum saving requirements,

Fig. 1. Biofuel policy-estimated emissions versus fossil fuel emissions[1]



[1] There are different values of emissions for wheat ethanol in the RE Directive depending on the type of production process considered; the lowest emission is obtained with straw as process fuel in CHP plant (26 g of CO2/MJ).
Source: our processing of data from RED and COM 595.

none of the (first-generation) biodiesel fuels would be able to fulfil the 35%, let alone the 50% and 60%, reduction requirement (Croezen *et al.*, 2010; Ahlgren *et al.*, 2014). Hence, a specific ILUC factor of 55 g of CO_2 per megajoule for oils plants would mean the end for biodiesel, plant oil-based HVOs and also for the not yet approved co-refining of plant oils in oil refineries (UFOP website[2]).

On the other hand, all types of ethanol fuels would be able to comply with the 35% minimum reduction requirement (except for wheat ethanol produced with a non specified process), whereas the 50% requirement will be difficult to fulfil for all but sugar cane ethanol. Instead, none of the first generation bioethanol fuels would be able to fulfill the 60% requirement.

However, many scientists questioned the validity of ILUC factors as efficient indicators of ILUC emissions for different reasons.

First of all, most models are not able to distinguish between dLUC and ILUC. This surprising statement also explicitly applies to the Laborde investigation (Laborde, 2011), the one used by the Commission for the ILUC proposal. The models are only able to measure total LUC (i.e. dLUC + ILUC). Why then we are talking about ILUC factor and not LUC factor? The reason is that dLUC is expected to approach zero by 2020 and hence ILUC will probably oc-

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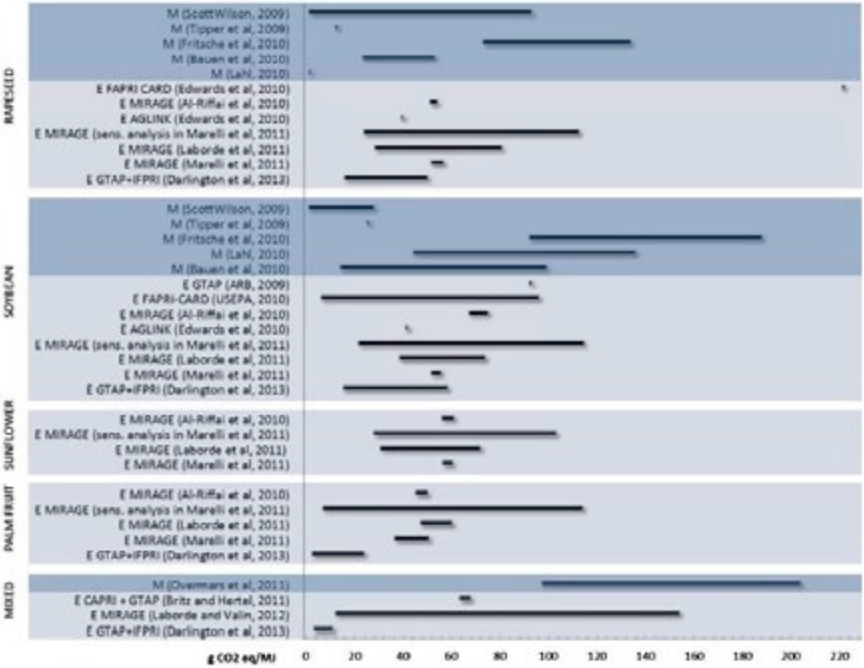
[2] <http://www.ufop.de/iluc-english/iluc-hypothesis/> (14/08/2014).

Fig. 2. Review of modelled greenhouse gas (GHG) emissions due to indirect land use change (ILUC) of biodiesel



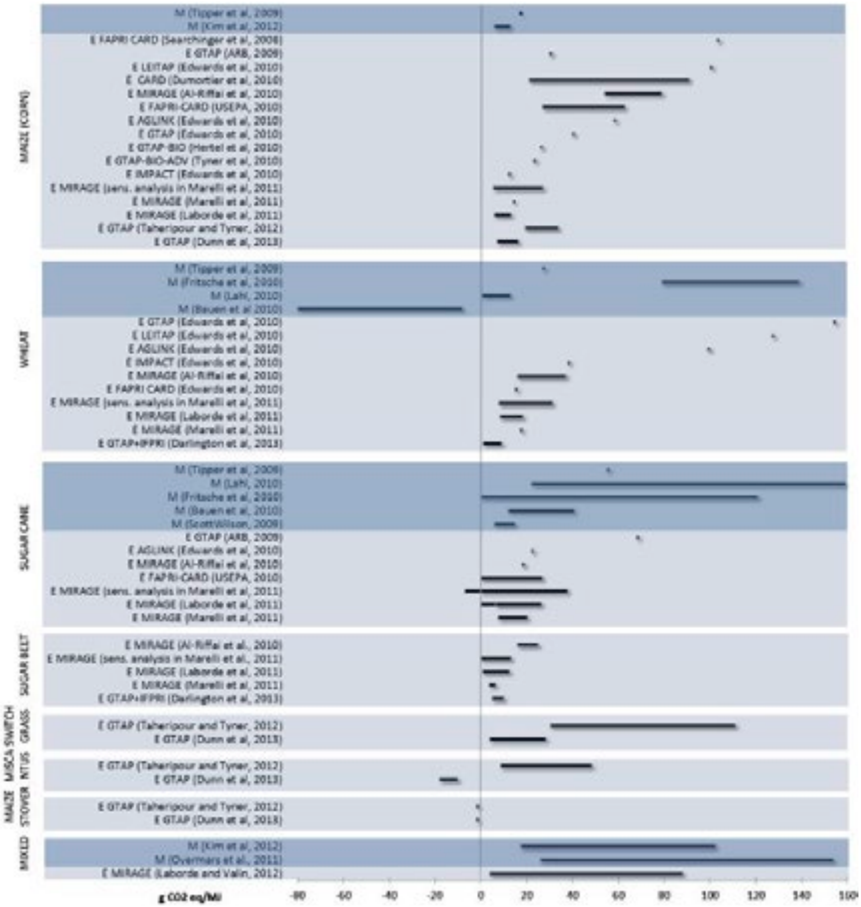
Source: Ahlgren *et al.*, 2014 (Values recalculated to a 20-year allocation base. Lines = intervals; dots= specific values. E = economic modelling and M = other modelling).

cupy a proportion of LUC so high to come very close to the (not very scientific) premise ILUC = LUC (Lahl, 2014).

Besides, the current ILUC estimations found in the existing literature are subject to enormous variations, even after attempts to harmonize these models (Edwards *et al.*, 2010).

Many attempts to calculate ILUC emissions have been made over time and in order to draw conclusions on the validity of this variable, many authors tried to compare the results of different models available in the international literature (Copenhagen Economics, 2014; Croezen *et al.*, 2010; DG Energy, 2010; Djomo and Ceulemans, 2012; Dunkelberg *et al.*, 2011; Edwards *et al.*, 2010; Lahl, 2010; Ostwald and Henders, 2014; Prins *et al.*, 2010; Berndes *et al.*, 2011; Dehue *et al.*, 2011; Malins, 2012; Lahl, 2014; Warner *et al.*, 2013; Wicke *et al.*, 2012; Di Lucia *et al.*, 2012). Not all these reviews have the same level of completeness and clarity.

Fig. 3. Review of modelled greenhouse gas (GHG) emissions due to indirect land use change (ILUC) of ethanol biofuels



Source: Ahlgren *et al.*, 2014 (Values recalculated to a 20-year allocation base. Lines = intervals; dots= specific values. E = economic modelling and M = other modelling).

The overview of LUC-related GHG emissions determined by different studies proposed here and provided in Figure 2 for biodiesel fuels and in Figure 3 for ethanol fuels, is based on the work of Ahlgren *et al.* (2014) since it is one of the most recent and complete.

The review shows that within the selected sample of papers, most modeling was carried out for ethanol, especially with maize as feedstock and that most studies employed general or partial economic equilibrium models.

The first thing that becomes clear looking at the figures is that large ranges in LUC-related GHG emissions are found within and across the different types of models and for the different feedstock conversion routes (Wicke *et al.*, 2012).

The largest variation in results was detected for wheat ethanol and soybean biodiesel. However, over time there was some convergence of results, particularly regarding ethanol from maize, which has undergone much modeling effort. Sugarcane and wheat showed similar patterns. In general, the values reported for biodiesel fuels showed greater variation than those for ethanol (Ahlgren *et al.*, 2014).

The ranges for the ILUC factors published are really enormous. Just the ILUC factor of biofuels (notwithstanding their GHG values for agricultural production, fuel production etc.) can be either some 200% below or some 1700% above the fossil fuels value. It can be positive or negative value. This clearly indicates the absence of any scientific robustness for claiming a particular ILUC factor (Finkbeiner, 2013).

Variations in estimated GHG emissions from biofuel-induced LUC are driven by the lack of a common modeling structure (different approaches and models exist), the differences in scenarios assessed, the assumptions that were made, distinct definitions (LUC), time horizon considered, disparities in data availability and quality, accounting for the effects of by-products and so on (Copenhagen Economics, 2011; Warner *et al.*, 2013; De Rosa *et al.*, 2014).

Therefore, comparing the results obtained from these studies is really a difficult and risky task.

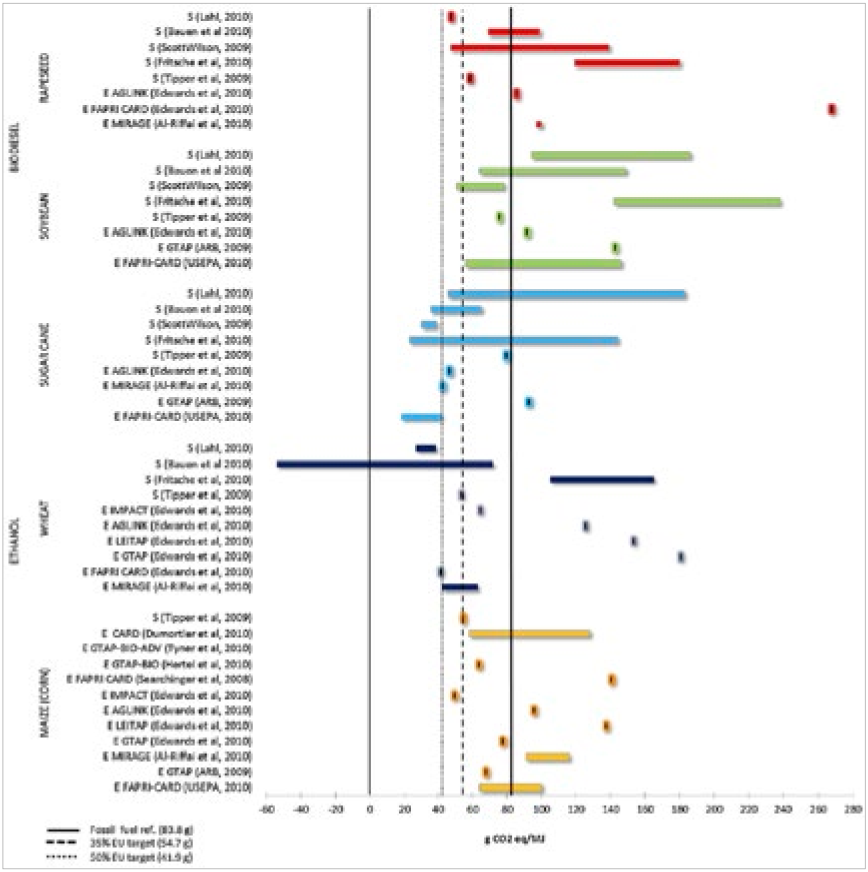
However, an interesting trend in the development of ILUC estimations based on economic models over time has been observed. Even though the time series is still short and all the uncertainties discussed above obviously apply to this trend as well, it is striking that refined and improved models in newer studies predict a lower ILUC impact compared to earlier esteems (Finkbeiner, 2013, De Rosa *et al.*, 2014).

Despite the high variability of results presented above, it has been observed that adding the direct emissions from the RE Directive to these modelling ILUC results, we can draw conclusions, about compliance with the minimum saving requirements, in many cases similar to those already observed for policy results (Fig. 1).

This is clear looking at Figure 4, which shows total biofuel emission values on the base of a literature review made by Di Lucia *et al.* (2012) which considered the same studies presented above, with the exception of more recent researches.

From this figure we can see that, according to many studies ethanol fuels should be able to comply with the 35% minimum reduction requirement, where-

Fig. 4. Total biofuels and fossil fuels GHG emissions including RE Directive emission savings requirements



Source: Di Lucia *et al.*, 2012.

as the 50% requirement will be difficult to fulfill for all but sugar cane ethanol (with a couple of results in favor to wheat ethanol too). Ethanol fuel results seem to be, at a certain degree, in line with the policy values (Ahlgren *et al.*, 2014).

In the case of biodiesel fuels, there is an even bigger variation of results from the models; in some cases, the policy estimates are higher than the range of values reported in the modeling exercises, in some other cases it is the contrary. In any case, it is quite safe to state that none of the biodiesel fuels would be able to fulfill the GHG reduction requirements of the EU directive.

3. Impact of biofuels on food commodity price

The price boom that emerged in the mid-2000s has been especially marked for agricultural commodity. In particular, the prices have been rather stable until the end of 2006, while from 2007 to 2008, they more than doubled, declining again in 2009, reaching the 2006 level. In the second semester of 2010, the price registered again an increase followed by a slight fall in 2011. A vast literature has emerged on the causes of this boom (The World Bank, 2008; Ranswant *et al.*, 2008; Sexton *et al.*, 2008; Trostle, 2008Abbott and di Battisti, 2009a; Balcombe, 2009; Sarris, 2009; Gilbert, 2010; Gilbert *et al.*, 2010; De Schutter, 2010; Jacks, 2010; Huchet-Bourdon, 2011; Muller *et al.*, 2011; OECD-FAO, 2011) some of which have been hotly debated as the role of speculation, the increased energy prices, the export policy changes, the declining US dollar, and especially, in the case of food commodities, the biofuels' role.

In recent years, the role of biofuel in the determination of the high agricultural commodity prices and in particular, the price linkages between the food, energy and biofuel markets, have become one of the issues most widely debated by energy, environmental and agricultural economists interested in the question of the sustainable development of biofuels (Kristoufek *et al.*, 2012a; Schimmenti *et al.*, 2012). The so-called «food crisis», which was characterized by sharply increasing prices for agricultural commodities and crude oil as well as for retail fuels and biofuels, captured a great deal of academic and political attention during 2008 and this debate on food versus biofuel issues has continued in more recent years affecting policies (Vacha *et al.*, 2012).

To date existing literature has fallen into two categories: one on the relationship between food commodity pricies and biofuel prices and another on the impact of increased biofuel production/consumption on food commodity prices. The first problem is investigated using the Time-series econometrics methodology (Zilberman *et al.*, 2012); the latter relies on the use of partial or general equilibrium models (Serra and Zilbermann, 2013).

3.1 Impact of biofuel prices on food commodity price

Although a great number of studies and reports investigate the dynamics of price level links between the commodity and biofuel sectors, current research has mainly concentrated on the US and Brazilian ethanol markets, while the European biodiesel market has not received much attention (Bentivoglio *et al.*, 2014). The biofuel-related price transmission literature has focused on studying price level links using cointegration analysis and VECM (Vector Error Correction Model). More recently, price volatility interactions have also been assessed by means of multivariate versions of ARCH (AutoRegressive Conditional Heteroskedasticity) or GARCH (generalized autoregressive conditional heteroskedasticity) models.

The link between EU biodiesel and agricultural commodity prices has been examined by Busse *et al.* (2010 and 2012), Hassouneh *et al.* (2012), Kristoufek *et al.* (2012b) and Vacha *et al.* (2012).

Busse *et al.* (2010) investigated vertical price transmission in the biodiesel supply chain during the rapid growth in German biodiesel demand from 2002 until its decline in 2009, by focusing on the connections between the prices of rapeseed oil, soy oil, biodiesel and crude oil. They found evidence of a strong impact of crude oil prices on biodiesel prices, and of biodiesel prices on rapeseed oil prices. However, in both cases, the price adjustment behavior was found to be regime-dependent. In a later paper, using a methodological approach which includes a regime-dependent MS-VECM, Busse *et al.* (2012) found evidence of cointegration between diesel and biodiesel prices, the latter being the endogenous variable, as well as between biodiesel, soybean and rapeseed prices, with the latter being the endogenous variable.

Hassouneh *et al.* (2012) studied the Spanish biodiesel industry. They found not only that there is a long-run equilibrium relationship between biodiesel, sunflower and crude oil prices but also that biodiesel is the only variable that adjusts to deviations from the long-run relationship and that sunflower oil prices are influenced by energy prices through short-run price dynamics.

Kristoufek *et al.* (2012b) investigate the relationship between biodiesel, ethanol and related fuels and commodity prices in the US and Germany using weekly, monthly and quarterly data. The analysis is based on minimal spanning and hierarchical trees. They find that biofuel is affected by food and fuel prices. However, biofuel prices show a limited capacity to determine food prices. The same authors also find out that the relationship between prices varies according to the data frequency used.

Vacha *et al.* (2012) analyzed the interconnections between ethanol and biodiesel systems and a wide range of related commodities, using wavelet coherence analysis. They find biodiesel prices to be more connected to fuel prices (German diesel), while ethanol is more related to food prices (corn).

Relatively to the Brasilian ethanol market and in particular the link between sugar and energy market, ethanol and crude oil/gasoline, was examined by Rapsomanikis and Hallam (2006), Balcombe and Rapsomanikis (2008), Serra *et al.* (2011b) and Serra (2011).

Rapsomanikis and Hallam (2006) and Balcombe and Rapsomanikis (2008) use ethanol, sugar and crude oil prices to investigate the Brazilian ethanol industry. Both articles rely on generalized (non-linear) versions of error-correction models. While sugar–oil and ethanol–oil are found to be nonlinearly co-integrated, ethanol–sugar prices are linearly co-integrated. Both articles provide evidence that crude oil prices drive long-run feedstock price levels, while the latter drive long-run biofuel prices. The Brazilian ethanol industry is not found able to influence crude oil long-run price levels.

A study on Brazil by Serra *et al.* (2011b) used weekly international crude oil and ethanol and sugar prices, observed from July 2000 to February 2008, to assess volatility spillovers in Brazilian ethanol and related markets. They found that the ethanol prices are positively related to both sugar and oil prices in equilibrium. Markets transmit the volatility in the oil and sugar markets to ethanol markets with minimal transfer of volatility in the other direction.

Another study on Brazil by Serra (2011) uses nonparametric correction to time series estimations and supports the long-run linkage between ethanol and sugarcane prices and finds that crude oil and sugarcane prices drive ethanol prices and not vice versa.

Relatively to the most recent time-series studies on US ethanol market, Zhang *et al.* (2009) focus on volatility of ethanol and commodity prices using cointegration, VECM and mGARCH models. The authors analyze weekly wholesale price series of the US ethanol, corn, soybean, gasoline and oil from the last week of March 1989 through the first week of December 2007. They find that there are no long-run relations among fuel (ethanol, oil and gasoline) prices and agricultural commodity (corn and soybean) prices in recent years. The same authors further analyze long- and short-run interactions with a use of cointegration estimation and vector error corrections model with Granger-type causality tests (Zhang *et al.*, 2010). They examine corn, rice, soybeans, sugar, and wheat prices along with prices of energy commodities such as ethanol, gasoline and oil from March 1989 through July 2008. They find no direct long-run price relations between fuel and agricultural commodity prices, and only limited if there are any direct short-run relationships.

Tyner (2010) finds that since 2006, the ethanol market has established a link between crude oil and corn prices that did not exist historically. He finds that the correlation between crude oil and corn prices was negative (−0.26) from 1988 to 2005; in contrast, it reached a value of 0.80 during the 2006–2008. However, only the price series are analyzed, which raises serious questions about stationarity of the data.

Serra *et al.* (2011a) uses autoregression analysis to identify the relationship between corn, ethanol, gasoline, and oil prices in the United States, using monthly data from 1990–2008. They found that the four prices are related in the long run through two cointegration relationships: one representing the equilibrium within the ethanol industry and the other representing the equilibrium in the oil-refining industry. The ethanol market provides a strong link between corn and energy markets, and the price of ethanol increases as the prices of both corn and gasoline increase, with the price of corn being the dominant factor when it is relatively high. Thus, the corn biorefineries may suffer losses when corn prices are high if the price of ethanol does not fully adjust to the rise in the price of corn. Saghaian (2010) supports cointegration between crude oil, ethanol, wheat, corn and soybean prices. Crude oil drives corn, soybean, wheat and ethanol equilibrium prices, while ethanol affects long-run corn prices.

Wixson and Katchova (2012) show on monthly US data from 1995 to 2010 that price of corn Granger-causes price of ethanol and that ethanol does not Granger-causes wheat.

Qiu *et al.* (2012) using a structural VAR model, provide evidence that fossil fuel and biofuel market shocks do not spill over grain prices.

Du and McPhail, 2012 conclude that ethanol, gasoline, and corn prices are found to be more closely linked. Specifically, ethanol (corn) shocks have the largest impact on corn (ethanol) price. The strengthened corn-ethanol relation can be largely explained by the new developments of the biofuel industry and related policy instruments.

All studies considered provide evidence of integration between the market of fossil fuel, biofuels and related agricultural commodities. Nevertheless, conclusions appear to be mixed and the results show that changes in biofuel prices have limited impact on food prices.

3.2 Impact of biofuel production on food price and security

Rapid growth in biofuel production has the potential to affect food security at both the national and household levels mainly through its impact on food prices. Expenditures on food amount to a large part of the budget of the poorest households, and so rising food prices threaten them with food insecurity, which is the lack of secure access to enough safe and nutritious for normal growth and development and for an active, healthy life (Timilsina and Shrestha, 2010).

One of the major forces through which the biofuel may contribute to the increase of the food prices is the diversion of land use from food-crops production to the production of biofuel feedstock (Janda *et al.*, 2011). This phenomenon takes place because increased demand of energy crops results in higher prices; higher energy crops prices in turn provide greater incentives for farmers to increase acreage. As more hectares are converted to the production of energy crops, fewer hectares are available for food crops that compete for the same land (Alexander and Hurt, 2007). Thus, the resulting scarcity of food crops drives food price inflation.

According to the reconstruction of von Witzke and Noleppa (2014), in the year 2008 the World Bank tried to give an explanation to these agricultural commodity price peaks and published a study in which more than 70% of the price increase at that time was attributed to the growth in global biofuel production (Mitchell, 2008). This study was harshly criticized for overestimating the impact of growing global biofuel production on agricultural commodity prices.

Another study published by the World Bank two years later, stated that the earlier study was likely to have overestimated the impact of biofuel production on agricultural commodity prices (Baffes and Haniotis, 2010). They argued that worldwide, biofuels accounted for only 1.5 percent of the area under grains/oilseeds and this raises serious doubts about claims that biofuels account for a big shift in global demand. Additionally, they reported that the effect of biofuels on food prices has not been as large as originally thought, but the use of commodities by investment funds may have been partly responsible for the 2007/08 spike.

An impact analysis, prepared by IPTS[3] (Institute for Prospective Technological Studies)[4] in 2008 shows that world market prices for biodiesel feedstocks are more sensitive to the EU's biofuels policies. This is because ethanol production is a relatively small component of total demand for the agricultural commodities that also serve as ethanol feedstocks, whereas demand for oilseeds and vegetable oils for biodiesel is a much larger component of total world demand for biodiesel feedstocks. They conclude that any direct pressure on global food markets due to EU biofuel policies will affect vegetable oils rather than grains or sugar (Fonseca *et al.*, 2010).

The OECD/FAO Outlook (2011) sustains that average crop prices over the next ten years are projected to be above the levels of the decade prior to the 2007/08 peaks, in both nominal and real terms. For example, average wheat and coarse grain prices are projected to be nearly 15-40% higher in real terms relative to 1997-2006, while for vegetable oils real prices are expected to be more than 40% higher.

Based on their review of 25 studies, Abbott *et al.* (2009b) identified three broad sets of forces that drove up food prices in 2008: the global changes in production and consumption of key commodities, the depreciation of the dollar, and the growth in the production of biofuels. Even in their follow-up study after the financial crisis, they found out that the key drivers of food prices remain the same: crop supply and utilization, the exchange rate and world macroeconomic factors, and the agricultural-energy linkage through the biofuel market.

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[3] Web site: <http://ipts.jrc.ec.europa.eu/>.

[4] The study was prepared for DG Agriculture and Rural Development (DG Agri).

In their synthesis of several studies that assessed the impact of biofuel development on food prices, Gerber *et al.* (2009) found that it is difficult to reconcile the various calculations of the impacts of biofuel production on food and commodity prices to-date. This is largely due to the intricate set of assumptions, the differences in the baseline scenario, and the projection horizon they are built upon. However, despite considerable differences in projection results, methodologies and assumptions, some common trends can be observed: the latest EU and US biofuel programs are expected to raise prices of vegetable oils the most, with smaller price increases for corn, wheat, and soybean; whilst the price of oilseed meals is widely predicted to decline. They also conclude that the future impact (i.e. beyond the short-term crisis) of the current biofuel policies and inherent production trends on food bills should decrease and 2007/08 should be considered the peak of food price growth.

Ajanovic (2011) considers that the most important impact factors on feedstock prices are biofuel production, land use, yields, feedstock, and crude oil prices. Ajanovic concludes that in the period 2000/2009, the increase, or better the volatility, of commodities prices has not been the only consequence of continuously increasing biofuel production, but by far the largest part of these volatilities was caused by other impact parameters such as oil price and speculation.

Sexton *et al.*, 2008 conclude that biofuels have a nontrivial impact on food security. They argue that underinvestment in research and overregulation of agricultural biotechnology led to a decline in productivity growth that is also responsible for higher prices and must be reversed if global food and energy security are to improve.

Most of the analysis reviewed in this section suggests that increased biofuel production could potentially have a significant impact on food-commodity price. However, although results vary, there is a broad agreement that the price increases are due to several factors including but by no means restricted to biofuels.

4. Conclusion

The sustainability of biofuels derived from agricultural biomass is widely debated nowadays. On the one hand the production of biofuels should ensure energy security for the historically non-oil producing countries, on the other hand it turns on the food versus fuel debate and the land use chance issue, generally responsible for a net loss in GHG emissions savings related to biofuel production and consumption.

The overview of LUC-related GHG emissions determined by different studies showed results with large variations within and across different types of models and for different feedstock conversion routes. The wide variation in estimates suggests that the measurement of ILUC is highly uncertain (Khanna *et al.*, 2011). There is agreement in the scientific community that the uncertainty of current ILUC factor is way beyond a level that is usually aimed for in quantitative science. Hence, scientific results do not deliver the answer from which policy makers easily can make policy options (Di Lucia *et al.*, 2012). There is a conflict between the demand from EU policymakers for exact, highly specific values and the capacity of the current models to supply results with that level of precision. As there is no consensus on ILUC predictions, it is arguable that any choice of ILUC emission factors will, to a large extent, be based on subjective decisions, even when objectivity is endeavored (Copenhagen Economics, 2014). This is why the European Commission attempt to impose very specific ILUC factors, is clearly at odds with the uncertainty in results emerging from modelling exercises to date (Ahlgren *et al.*, 2014). As a consequence, using such uncertain ILUC factors as a basis for regulation could weaken the credibility of EU biofuel policy (Copenhagen Economics, 2014).

Concern over competition between biofuels and food production has been particularly acute, given the overwhelming use of food and feed crops for biodiesel production (HLPE, 2013). To date, the literature has been very wide-ranging. According to Hochman *et al.* (2011) and Kristoufek *et al.* (2011), the relationship between fuels and agri-food commodity prices depends on the market analysed (EU, US and Brazilian context), on the types of commodities, on the specification of the model and on the time series data and observation period (weekly, monthly or quarterly). Moreover, the dynamics of commodity prices are complicated and different factor may be affecting these markets (Nazlioglu *et al.*, 2012).

The various calculations of the impacts of biofuel production on the mid-term projections of food and agricultural commodity prices are difficult to reconcile. This is largely due to the specific assumptions underlying each model, the scope of the studies (national/international), their time horizon, the choices of different policy scenarios, or even more simply the definition of «food prices» and of aggregate commodity prices (Gerber *et al.*, 2008). For similar reasons, studies evaluating the impact of biofuel production on food and commodity prices to date do not provide a clear consensus.

On the one hand, this review underlines that the time-series analysis linking food and fuel prices shows that biofuel prices are increasing with both fuels and food prices, but it also shows that changes in biofuel prices have little impact on food prices. On the other hand, the impact of an increasing production of first generation biofuels on food prices is not negligible and varies across crops and locations. For example, if biofuel crops are cultivated exclusively on set-aside lands or marginal lands, with little competition with food crops, the impacts on food prices can be theoretically minimal. But in reality biofuels may still compete for other resources like water or labor and thus impact food production (Rajagopal *et al.*, 2007).

The main findings, that emerged from the literature review, have important policy implications. In order to promote biofuels that deliver substantial GHG savings (including ILUC emissions) and reduce competition with food crops, the Commission developed a Proposal of Directive (COM 595, 2012) with the aim of limiting the contribution of first generation biofuels towards attainment of the targets in the RED in favor of 2nd and 3rd generation biofuels. However, the effectiveness of this policy measure has been criticized since the production of advanced biofuels is still not economically sustainable, so at the moment 1st generation biofuels seem to be the most viable agro-industrial chain.

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