System dynamics modelling for assessing promotion strategies of biofuels used in land transportation

Abstract

This article presents the development and use of a system dynamics model of the interactions of the food commodities and biofuels production systems. The principal aim is to develop a sense of the mechanisms responsible for the impact of biofuels on the production output and prices of food commodities. The model and the associated discussion are confined to biofuels for the transportation sector of the European Union. Simulations of the model with incentive policies for promoting biofuels in the European Union showed that beyond a certain point, the rate at which biomass production expands can be problematic with regard to land availability for agricultural products grown for human consumption. Nevertheless, simulations indicated that process technology increasing the productivity of biofuel production can act as a balancing factor.

Keywords: biofuels, policy, land transportation, system dynamics, critical realism

1. Introduction

For several years, biofuels have been considered as an alternative source of energy and there have been numerous efforts for their development and adoption. The case of Brazil after the oil crises of the seventies is the most characteristic. These efforts, however, were not followed through in the eighties, and biofuel adoption declined as the discovery of oil fields outside OPEC drove oil prices down. The reasons for the current renewed and increased interest and developments in biofuels can be attributed to seven factors: a) high fluctuating oil prices, b) an increase in total human activity in every region of the planet that contributes to global warming (IPCC, 2007), c) the exponential population increase, d) an increase in per capita needs, e) incomplete knowledge of the limits to natural resources (Meadows et al., 2004; Rockström et al., 2009) both from those involved in managing them and those who use them (Bartlett, 2004), f) security of energy supply (Umbach, 2010) and g) additional income source for the agricultural sector.

As a response to these issues, it is anticipated that the adoption of biofuels will contribute to energy security, when oil production will peak. It will also contribute to the reduction of CO_2 emissions (European Commission, 2001a; Ignaciuk et al., 2006). In addition to the positive contribution in dealing with the aforementioned problems, biofuels can be used to support existing human activities, as more energy will be available. At the same time they pose new demands for land expanses. Hence, it is evident that energy policies should take into account related issues of human nutrition, health, etc.

Incentives provided from governments and international organizations have resulted in a shift towards biomass production at the expense of other more traditional agricultural products. Subsequent rises in food commodities prices and raw material shortages were attributed wholly, or in part, to the distribution of cultivable land for biomass and related products. Future scenarios by certain analysts on the ability to increase yields and, therefore, agricultural production, paint a rather grim picture (Timilsina and Shrestha, 2011). Are these worries about prices justified? which mechanisms are responsible for the shortages and increased prices already observed, for which future phenomena will these mechanisms be responsible, and how these mechanisms must be configured through energy policy instruments for reversing trends? Research into these issues, principally for the case of the US markets, have already been accomplished using statistical and/or econometric models (e.g. Ignaciuk et al., 2006; Belcombe and Rapsomanikis, 2008; Zhang et al., 2010) and various dynamic partial equilibrium models (Witzke et al., 2008). System dynamics has been used (Schade and Wiesenthal, 2011) but for looking on the effect of fossil fuels on biofuels. Sandvik and Moxnes (2009) look at the interaction of prices of oil, food and biofuel without explicitly incorporating land use dynamics. At a larger scale, in the practice of policy making biofuels have been debated at institutions such as the European Parliament and direct reference to predictable large-scale detailed models aiming at predicting and assessing their impact has been made (Fonseca, 2010).

The current article is an attempt to complement these efforts in terms of scope. That is, to answer the same questions by investigating possible generating mechanisms expressed as dynamic hypotheses which are tested with the help of a system dynamics model. The model is calibrated using data for the European Union fifteen oldest member states (EU 15). EU 15 data were used because it was the most complete and reliable long-term data set available. Beyond this, the contribution of the paper is to demonstrate how a systems approach operationalised through system dynamics modelling can be used to explain and explore similar situations in energy systems transitions (Geels, 2004; Kern and Smith, 2008; Meza and Dijkema, 2009).

The paper is organised as follows: In the following section (Section 2) issues related to land use for biomass are discussed. In Section 3, a perspective on the dynamics of biofuels production is presented, whereas in Section 4 the development of the system dynamics model and the basic assumptions embodied in its structure are discussed. In Section 5, the results of the simulations are presented and discussed. Finally, in the last section, discussion is made and conclusions are drawn about implementing policies that support and reinforce the adoption of biofuels as a source of energy and hence the questions posed earlier are answered.

2. Biofuels and Land Availability

Depending on resource availability, biomass cost and energy produced, conversion technologies, as well as social and institutional factors, several studies project global biomass energy production penetration in the range of 10-50% of total energy demand (Hoogwijk et al., 2005). Clearly, the bioenergy potential also depends on global land availability and land yields (Berndes, 2003), and on the competition with other technologies, such as solar and wind energy, both set to develop rapidly. The impact of a continuously growing bioenergy sector on other land uses, and its related socioeconomic effects have not been investigated sufficiently, although it has become apparent that land constraints will lead to competition between food and fuel production (Peters and Thielmann, 2008), making the issue of providing food in a planet with a constantly increasing population one of great importance (Lotze–Campen et al., 2005). Whether agricultural production and yields will increase sufficiently in order to supply demand is contested (Timilsina and Shrestha, 2011). A study that looked into the complexities of biofuel and climate influences on agricultural production concluded that if the expansion of biofuels based on agricultural crops, reaches the levels stipulated in the mandates and targets established in numerous countries, then this additional burden on crops production will have a 'significant impact on the world food system' (Fischer, 2009). The study goes on to project biofuels and climate change impact on agriculture with the former having a large impact up to 2030 and reducing with time while the latter following the opposite with significant effects in the long term. In terms of total production it is been estimated that in order for food supply to meet demand on a global scale, total production should double by 2025.

By contrast, however, there are researchers claiming that land availability is not a constraint for biofuels, as productivity will continue to rise (Timilsina and Shrestha, 2011). It is a fact however that world food prices has increased significantly from 2002 to 2007 primarily as a result of increased demand for cereals and oilseeds for biofuels, low world food stocks, reduced harvest in some locations, for example in Australia and Europe due to drought conditions, record oil and fertilizer prices and world market speculation. What exacerbates the problem of supplying food needs and the associated requirements for resources are the differences in diets followed around the world. In the following section the dynamics of acreage availability and its role in potential competition with existing land use patterns and technological knowhow are examined, as well as the potential of focusing on second generation biofuels.

3. The Dynamics of Biofuel Supply & Demand in the EU

The conditioning of developed countries on hydrocarbons is a well known fact. For example, from the 1970s and onwards, US imports more than 50% of the oil it consumes. The European Union member states also rely significantly on fossil fuels, as net imports of all energy sources amounted to 52% of total gross inland consumption in 2004 (Eurostat, 2007a) and 83% on crude oil and petroleum products in 2007 for EU 25 (European

Commission, 2010). What intensifies the problem for US and EU is the increasing population trend (Eurostat, 2008a) and increasing mobility by land, sea and air that inevitably lead to greater fuel consumption. EU population is projected to reach four hundred million inhabitants in 2030 for Europe, and between eight and ten billion on a global scale (United Nations, 2006). These trends are bound to keep the demand for fuels increasing. As hydrocarbon sources are not renewable, peaking oil production in the future (Witze, 2007; Aleklett et al., 2010) will put countries without domestic oil sources at a disadvantage and those that have them in a beneficial position. In this context biofuels are portrayed as a sustainable solution to an uninterrupted energy supply, as the rate of discovering new oil fields declines (Janssen and Rutz, 2007).

In the European Union, substituting fossil fuels with biofuels has been anticipated to contribute to transport emission reduction, improve energy security and development of rural communities (Ryan et al., 2006*)*. Adoption of biofuels for transportation needs has been planned with set targets for 2005 (2%), 2010 (5.75%) and 2020 (10%) (European Commission, 2001b). However, these targets seem unachievable as only 1.2% coverage was achieved in 2005 (European Commission, 2006a). Bringing about such a change is not an easy task as existing energy and transport systems are characterized by lock in and resistance to change (Unruh, 2000). The development of energy plantations has been successful so far only in specific countries like Brazil (Ryan et al., 2006), China and Sweden, where significant governmental incentives and subsidies or tax breaks have been given (Wright, 2006; Peters and Thielmann, 2008).

As indicated in the introductory section, the food commodities and biofuel production systems interactions have already been studied, principally for the case of the USA market, using statistical/econometric modelling approaches (Ignaciuk et al., 2006; Belcombe and Rapsomanikis, 2008; Zhang et al., 2010). These methodological approaches solely aim at predicting future system behaviour on the basis of a flat ontology of observed events and their correlations. As such, they do not pay particular attention on the causality between events or patterns producing mechanisms and the observed events per se (Mingers, 2004; 2006). In addition, even at the event level, they assume an 'open-loop', i.e. linear, causality and closure of the system under study (i.e. it is assumed that there are no dynamic interactions with the environment, or that interactions are constant and predictable). Clearly, for all the above reasons, these approaches fail to explain why events (food commodities shortages and prices inflation) are observed, and/or why they will be observed.

Consequently, system dynamics was used for modelling the biomass production system under land constraints. Data from international organizations and other sources were compiled to construct and inform the model. Several scenarios were tested for different policies, taking into account developments in biomass processing technologies, first to justify the mechanisms as representation of reality and then to observe the behaviour of the system in the course of time (section 5).

In the causal loop diagram of Figure 1, the biofuel and the food commodities production and consumption systems are presented. Arrows indicate a cause and effect relationship among variables, and signs indicate positive (reinforcing) or negative (balancing) effects. The right hand side of the diagram represents the dynamics of demand whereas that on the left, the production and land use processes. *Fuel demand,* ceteris paribus, is affected and increases with increasing *population, Cars per capita* and *km per capita*. In contrast, gasoline demand should decrease as the fuel mix supplied to the market has an increased biofuel content inline with regulation. Targets set by the European Union determine the desired percentage of biofuels used in mix with conventional fuels (*EU fuel mix*) and hence the gap between aimed and attained volumes of biofuel usage. *Biofuels inventory* and *food inventory* are key factors whose variations regulate prices and the profitability for farmers, for whom it is assumed that they operate as rational profit maximizers using land according to foreseeable profits (left side part of diagram). It is expected that these inventories, influence the timing of the observed effects of different policies. They act as buffers between production and supply and absorb variations on both sides. An increase in *Biofuel demand* depletes *Biofuels inventory* and causes *Biofuel price* to increase and subsequently *Biofuel crop land* to increase. This increase in land dedicated to biomass production takes place via *Land transfer to biofuels* with a corresponding decrease from the expanses of *Food crop land*. The need for cultivable land is reinforced by the simultaneous increase in population. Government and EU policies are represented through the variables *Incentives for biofuels* and *Biofuel technology and management capabilities*. The former is a direct policy instrument whereas the latter is an indirect one resulting in the funding of related R & D projects. These two instruments are competing for resources and have contrasting effects, as incentives increase land use whereas technology increases the yield of the existing land.

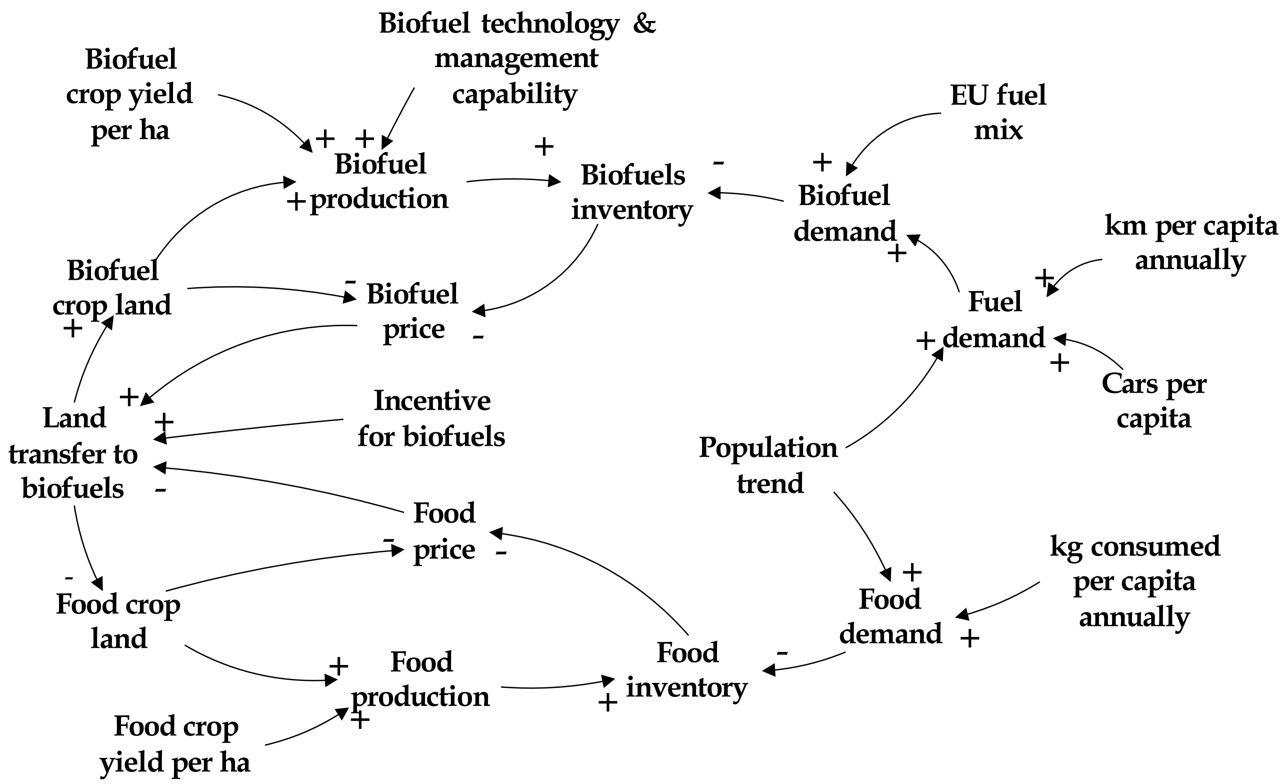

Figure 1 Causal Loop Diagram (CLD) for biofuel adoption in land transport

Based on the structure of the causal loop diagram as a representation of reality, a rapid increase in biofuel production does imply a rapid increase in demand for land as it has already been observed in many cases. The diagram suggests that the same pattern is bound to continue in the future assuming if only first generation biofuels are available for commercial use (Tzimas et al., 2004). According to some estimates, however, the situation will improve significantly with regard to land use when second generation biofuels become commercially available (European Commission, 2006a; Charles, 2007). This is also suggested by the structure of the causal loop diagram, as *Biofuel technology and management capability* improves yields in *Biofuel production* thus covering the *Biofuel demand* with less land area (Biofuel crop land). The development of the exact model described below and its calibration and simulation provided more concrete arguments for these observations.

4. Presentation Of The System Dynamics Model

The model constructed is based on the analysis of the biofuels issue summarized by Sorensen (2007) and follows the logic of the causal loop diagram (Fig 1). In Figure 2 an aggregate structure of the system dynamics model is shown. The two competing demand on land described in the previous section have been integrated to an increasing *EU population*. This affects the use of land for biofuel production (*Biofuel demand)*, the land use for grain production (*Food demand)*, as well as the subsequent flow of land between the two different uses. Note that the land flow, is bidirectional.

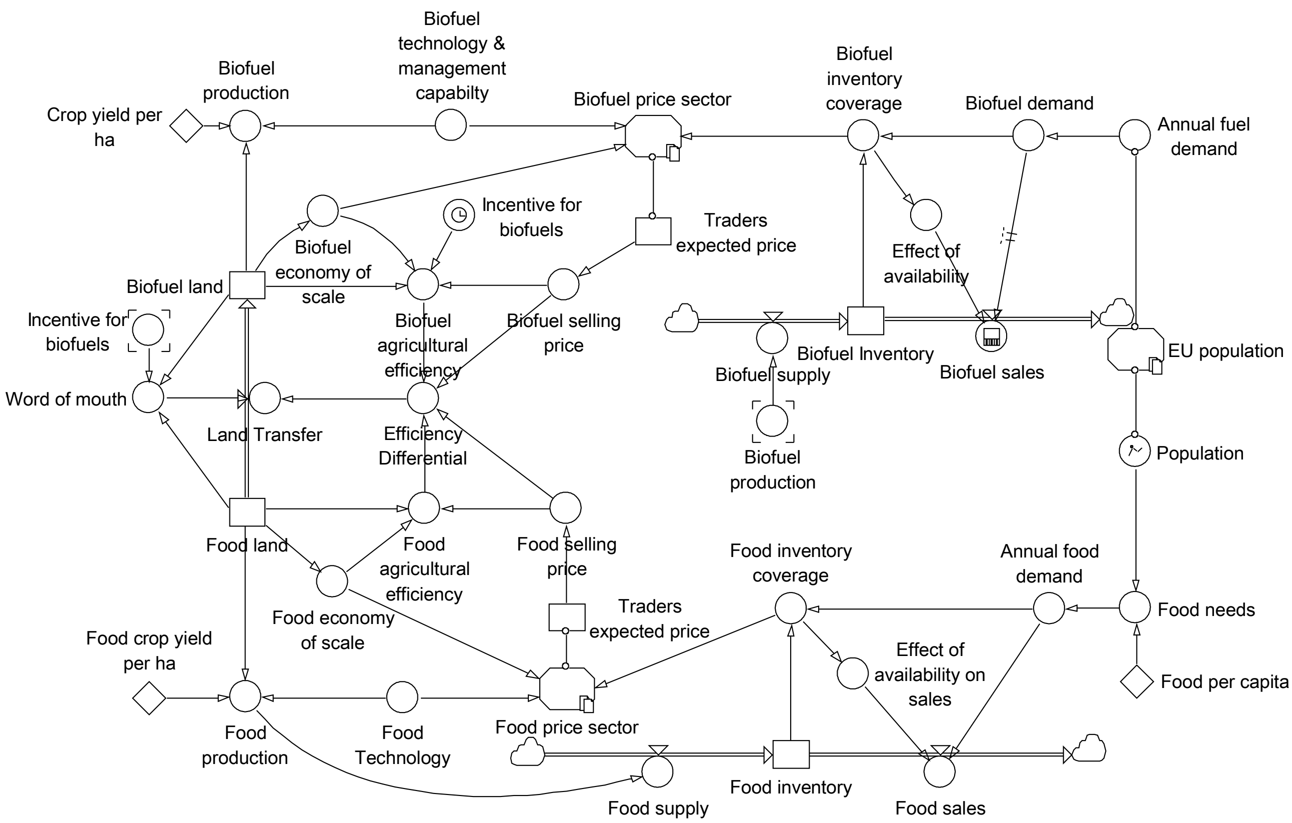

Figure 2 Biofuel production and consumption stock and flow representation

The demand for food commodities is a function of population and European per capita annual food demand, which is considered to be steady for the EU 15 inhabitants with respect to quantity and diet mix (animal/grain based food). Superimposed on that is a safety factor of 1.36, which is lower than the value of two cited in literature (Hoogwijk et al., 2003; Wolf et al., 2003). The *annual fuel demand* for transport is calculated by

$$N*S_{cap}*V_{eff}*V_{cap} \qquad (1)$$

where N is the population size, S_{cap} (annual km covered per capita) is constant at 15,000 km, and cars per capita (V_{cap}), and average fuel consumption per car (V_{eff}) follow linear trends. The average fleet fuel consumption is assumed to decline with time. This assumption is based on the existence of a voluntary agreement between the European Union and the three associations of automotive manufacturers (ACEA, JAMA and KAMA), which requires a gradual decrease in average vehicle emissions and as a result average fuel consumption per car is expected to fall as well (European Commission, 2000; 2001c; 2002; 2003; 2004). The number of cars per capita is assumed to increase approximately linearly up to 2006 with a value of 0.506 (the year for which data are available). After that, a slower increase is assumed until 2050, where a value of 0.552 is reached. This trend is modeled using data from European Automobile Manufacturers Association (2007) and Eurostat (2007b). For the population (N), Eurostat data for the period 1996 to 2007 were used, while for the following years, Eurostat projections were adopted up to the year 2050 (Eurostat, 2007a). An assumption made is that there are no significant barriers, social or otherwise, neither in 1st generation biofuel adoption, nor in the transition from 1st generation to 2nd generation biofuels (McCormick and Kaberger, 2007; Berndes and Hansson, 2007). As the yield in 1st generation biomass conversion technologies will remain relatively constant and 2nd generation technologies are not yet commercially available, the increase in the use of biofuels will be covered by converting land used for grain production to biomass production (this assumption is relaxed later on). A leverage point towards achieving this is financial incentives for farmers, in order to create favourable market conditions for biomass. While, there is little evidence of homogenization of incentives and taxes in the EU (Steenberghen and Lopez, 2008), in the model incentives are assumed to be uniformly implemented for all EU 15 countries, and an average incentive scheme was implemented. This varies with time as shown in the graph below (Figure 3).

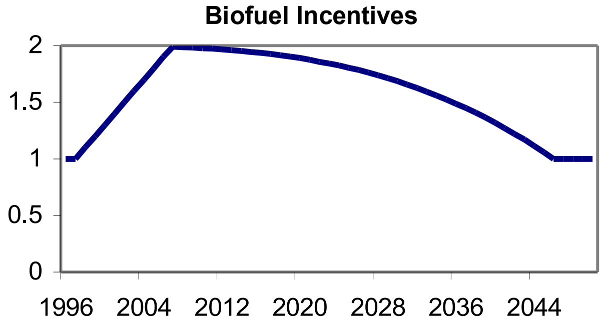

Figure 3 Magnitude of incentives offered for biomass production.

The magnitude of incentives is represented in the vertical axis. The value of 1 is the reference level where free market competition conditions (prices of food vs biofuel) are assumed. Incentives are assumed to increase until 2010 tilting the land transfer flow towards biofuel use. The assumption underlying this pattern is that incentives are temporary and as soon as biofuels are commercially viable, they will be reduced in order to let the market operate undistorted. The total cultivable land for cereal production used in the model was that of the EU 15 in 2000 (49,000,000 ha) (IEA, 2004). In the model, the rate at which land shifts from one use to the other is determined by the *Efficiency differential* between *Biofuel agricultural efficiency* and *Food agricultural efficiency* and the difference between food commodities and biofuels prices. Prices are not taken to represent some precise commodity value at the time the simulation starts (1996), but they represent the aggregate relative economic value between food and biofuels as everyday consumer products. The efficiency relationships for biofuel and food commodities are:

$$\text{Biofuel agricultural efficiency } B_{eff} = B_{price} * (K/B_{land}) * B_{scale} \quad (2)$$

$$\text{Food agricultural efficiency } F_{eff} = (F_{price}/F_{land}) * F_{scale} \quad (3)$$

where B stands for biofuel and F for food. K is the magnitude of the incentives given to biofuels (Figure 3). The subscript scale refers to the scale of the economic activity of the two variables (Biofuels and food) and is calculated by:

$$F_{scale} = F_{land}/\text{Total land} \qquad (4)$$

$$B_{scale} = B_{land}/\text{Total land} \qquad (5)$$

The efficiency differential E_{diff} is thus calculated from:

$$MAX(F_{eff}, B_{eff})*MAX(F_{eff}/B_{eff}, B_{eff}/F_{eff})*\textit{Land use change direction}*P_{diff} \qquad (6)$$

where *Land use change direction* is a variable that operates as a switch allowing land transfer to *Food land* when F_{eff} is higher than B_{eff} or to *Biofuel land* when B_{eff} is higher. The effect of the price difference P_{diff} in (6) is calculated from:

$$MAX(B_{price}, F_{price})*MAX(B_{price}/F_{price}, F_{price}/B_{price}) \qquad (7)$$

The price for biofuels and food commodities is influenced by two variables: *Sensitivity to production* and *Sensitivity to coverage*. Actual levels of biofuel and food commodities inventories are assumed to take a month to be determined with sufficient accuracy. For food, *Sensitivity to production costs* is assumed to have a low impact on price, as productivity improvement is not included (though it exists it is rather small) in the model. Hence, a worst case approach is adopted. For biofuel production, however, *Biofuel technology and management capability* is one of the contributing factors for market diffusion as alternative fuels. In the scenarios that were simulated, *Biofuel technology and management capability* improves linearly with time. In the model, factors that affect biofuel production include: *Biofuel technology and management capability*, *Crop yield per ha* (lt/ha), and *Biofuel crop land* (ha). The productivity of biomass cultivation (*Crop yield per ha)* is assumed to take the average value between that for bioethanol and that for biodiesel (IEA, 2004). This is so, because the European passenger car fleet is approximately equally spread between cars with diesel and gasoline engines (European Commission, 2006b). Therefore, it is assumed that land expanses are equally allocated in order to cover biodiesel and bioethanol demand.

The biomass yield improvement due to anticipated temperature or precipitation increase is not included in the model, despite the fact that it will have an effect (Parry et al., 2004). As there is no consensus value for the annual biomass production, a range between 3700kg and 5500kg per ha is used (Wolf et al, 2003; Gillard, 2002; Hall and House, 1995). In the model, biofuel demand depletes *Biofuel inventory* and as a result the corresponding price rises, the *Biofuel agricultural efficiency* increases, and additional land expanses are added to biomass production. Demand for food increases with population and, subsequently, the food commodities prices increase the *Food agricultural efficiency*. In initializing the model, food inventory is assumed to be enough to cover demand for a year, assuming 1997 demand levels and surpluses are not taken into account as it has been done in other studies (Wolf et al., 2003; Hoogwijk et al, 2003). Per capita annual food needs are assumed to be constant in the EU (Gerbens–Leens and Nonhebel, 2002), and in the model they range from 420 kg (Gillard, 2002) to 430 kg (Alexandratos and Haen, 1995) per capita per year. For the purposes of the model it is assumed that the total cultivable land is not affected by other physical phenomena, such as desertification which is considered to be a problem at present (Lotze – Campen et al., 2005). The rate at which change of land use takes place is given by:

$$LUC = E_{diff} * \text{word of mouth} \qquad (8)$$

The word of mouth, operates bi-directionally in the model. The corresponding equation is:

$$\text{Word of mouth} = B_{land}*F_{lanf}*I*A \qquad (9)$$

where I is the interaction rate between farmers set to the value of 40 (a moderate value assuming that farmers live and produce in small communities), A is the adoption percentage, set to 20% and varying with incentives. It is assumed that oil supply has no direct effect on the biofuel supply chain, despite the fact that, as oil prices rise, the level of subsidies required to compensate the cost difference between biofuels and fossil fuels is reduced (Ryan et al., 2006). The effect of oil prices on grain crops (corn and soybeans) is also excluded (Nazlioglu, 2011).

5. Simulating Different Policies

Two simulation scenarios regarding the effect of incentives for biofuel production were examined. In the first, implementing strong incentives, whereas in the second weak ones. With regard to biofuel productivity, two cases were tested. First, a steady improvement in *Biofuel technology and management capabilities* is tested and then 2nd generation biofuels are assumed to become commercially available in 2020, increasing biomass productivity (see table 1). Both cases were tested under both of the incentives-strength scenarios. Simulation time was set to 54 years (1996-2050) to examine long term dynamics and related long term policy making and strategies. The variables monitored were *Biofuel price* and *Food price*. In every case the initial *Biofuel price* was set to twice that of *Food price*. *Food crop yield per ha* was set to 4500kg/year (Hall and House, 1995), which was approximately the average of the values provided by Gillard (2002) and Wolf et al. (2003).

Variable	Range of values (units) - reference
Food crop yield	3700 (kg/ha/year) - Gillard (2002) 4500 (kg/ha/year) - Hall and House (1995) 5500 (kg/ha/year) - Wolf et al. (2003)
Food per capita (kg)	420 (kg/year) - Gillard B., (2002) 430 (kg/year) - Alexandratos and de Haen (1995)
Incentive build up time	10 (years)
Incentive implementation year	1997 - 2007
Fallow land introduction	0 (ha) – 2e6 (hectares) - EU press release (2007)
Biofuel management & technology	1^{st} generation, 1^{st} initially & 2^{nd} generation in 2020
Biofuel incentive magnitude	0, 1(weak), 2 (strong)

Table 1 Range of variables used in scenarios and range of values tested.

5.1 The Dynamics Of Biofuel Prices

Figure 4 shows the average biofuel price as an index from the starting point in 1996, as well as the maximum and minimum values for all possible scenarios and cases mentioned above, for the entire range of crop yields and annual per capita food needs. The range of possible values increases with time as the impact of those factors modeled begins to manifest (e.g., population, biofuel incentives). The incentives for biofuels reach their maximum value in 2006 and this causes the slight upsurge in biofuel prices as incentives affect land transfer in more than one ways. As a result, the shift of land use to biomass production after 2006 is almost insignificant. What keeps biofuel prices from rising after 2006 is improvements in *Biofuel technology and management.*

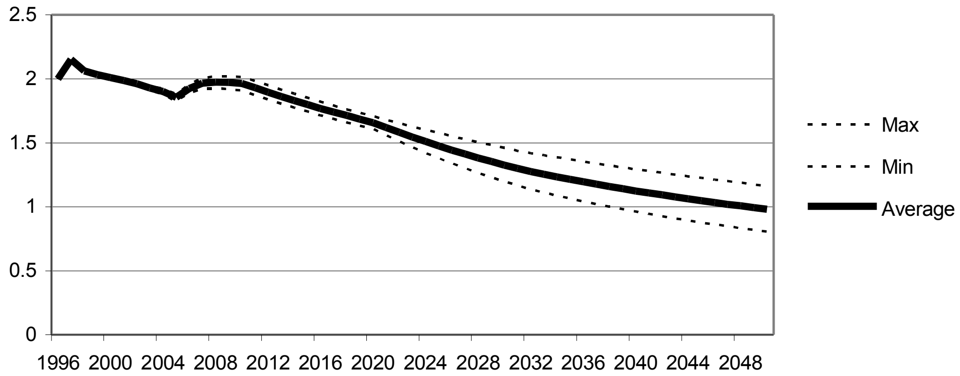

Figure 4 Variation of biofuel price for the range of simulations.

The duration of biofuel incentives (Figure 3) seems to make no significant difference in biofuel prices. The range of values tested was five to ten years. Experiments with the implementation time showed that the earlier the incentives start being developed, the lower the prices attained in the long term as economies of scale become more influential. In summary, the profile of biofuel price dynamics is similar to that of any new product with high values near the time of its launch, and then gradually decreasing as economies of scale develop. What is interesting however, is that the biofuel penetration targets as set by the EU are not met in any of the scenarios and cases tested with an annual land yield for food of 4500kg per hectare, as biofuel penetration does not exceed 3 %. Thus in order to meet these targets EU countries have to rely on imports (Banse et al., 2011), an option that was not included in the model.

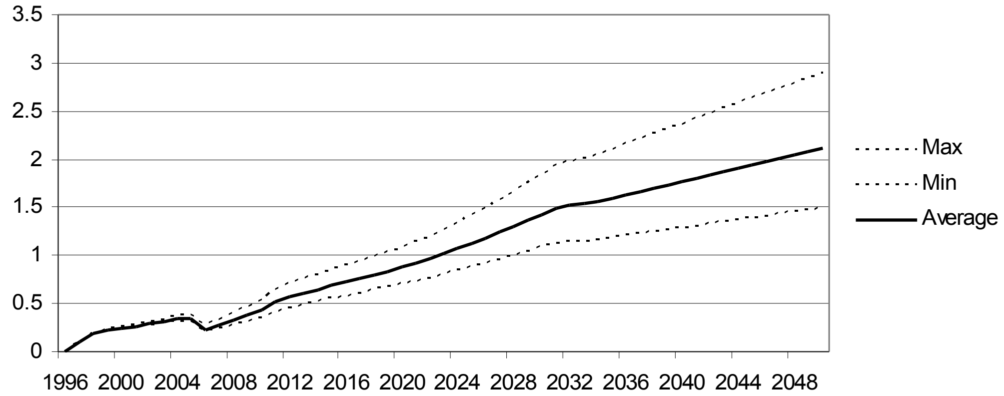

Figure 5 Percentage of biofuels in entire fuel market in EU 15 for the simulation period.

5.2 The Dynamics Of Food Commodities Prices

Figure 6 shows the variation of the average food commodities price as an index from the starting point in 1996, as well as its maximum and minimum limits, for the range of scenarios and cases considered. In every case, the simulation results indicate that food commodity prices increase (as a result of biomass cultivation after 2008) as population and biofuel incentives increased (Figure 3). Both increase simultaneously and reinforce the demand for more land, which apparently is not available. Prices seem to decrease after 2030 when the population of EU 15 is projected to reach a maximum.

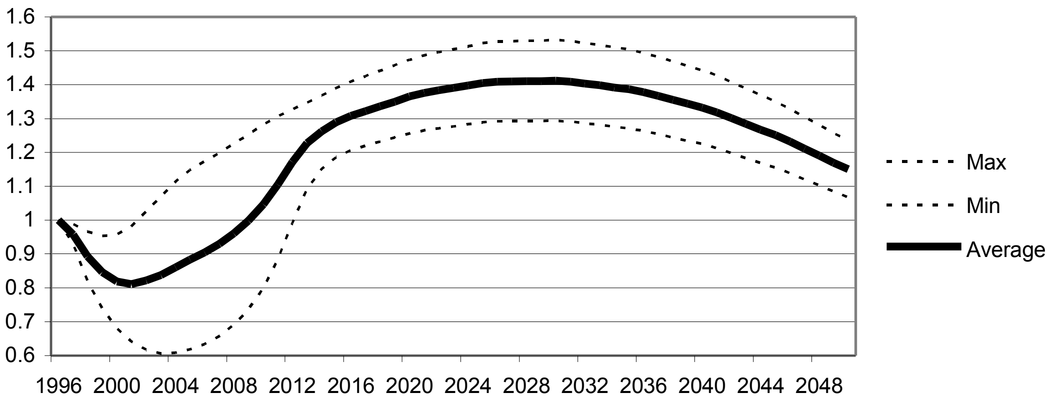

Figure 6 Variation of food price for the range of simulations.

Simulations indicated that reducing the magnitude of incentives had an impact on food commodity prices, more so than in the case of biofuels. The results are shown in Figure 7 for strong, weak and no incentives in place, with 4500kg/ha annual biomass production yield, and 420kg food per capita needs, with 1st generation biofuel processing technology only.

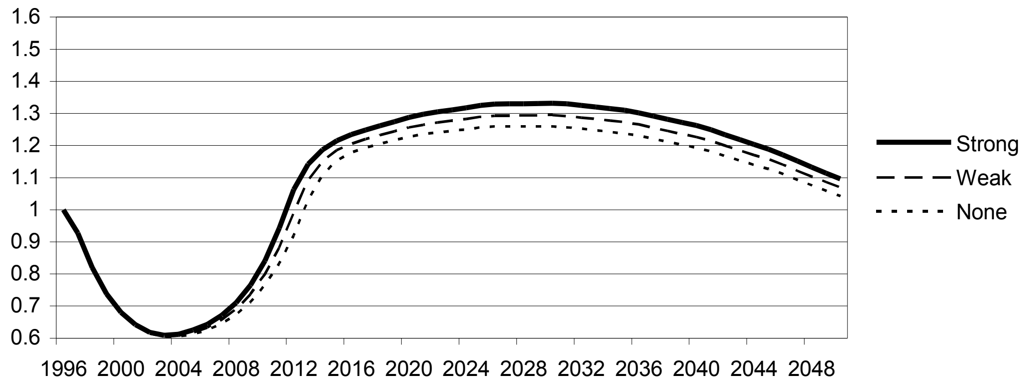

Figure 7 Food prices under different biomass incentives.

As expected, strong incentives lead to higher food commodities prices as land is transferred to biomass production. This land transfer does affect food stock coverage which is high between 1996 and 2008 but begins to diminish afterwards affected by the simultaneous increase in population. This result holds irrespective of whether second generation biofuels are introduced in 2020, and for the whole range of crop yield values and annual per capita food needs. Even with no incentives food prices still increase, due to population increase and insufficient cultivable land for covering food demand. Thus the removal of incentives on biofuels only works to delay food price increases, not to avoid them just as in the case of Sandvik and Moxnes (2009).

The delayed introduction of incentives, does result in slightly lower food prices and slightly higher biofuel prices. Examining the effect of longer development times (10 - 20 years) simulation results show again that delaying incentive development does result in slightly lower food prices and higher biofuel prices. Delaying the introduction of incentives by a decade, results in slightly lower food prices, considering only first generation biofuels and keeping incentive development time at 10 years.

In order to test for the timing of a potential decision on relaxing land constraints, simulations were executed in which the assumption of fixed land area was relaxed. Following bad crops and low agricultural product inventory levels, the European Commission (2007) indicated that fallow land in the European Union 27 member states should be put back into production to balance them. The total fallow land area is approximately between 1.6 and 2.9 ha million in EU 15. In the model an addition of 2 ha million to land used for grain cultivation in 2008 initially (a somewhat conservative value). While this makes very little difference with regard to biofuel prices, it does have an effect on food prices as shown in Figure 8 below.

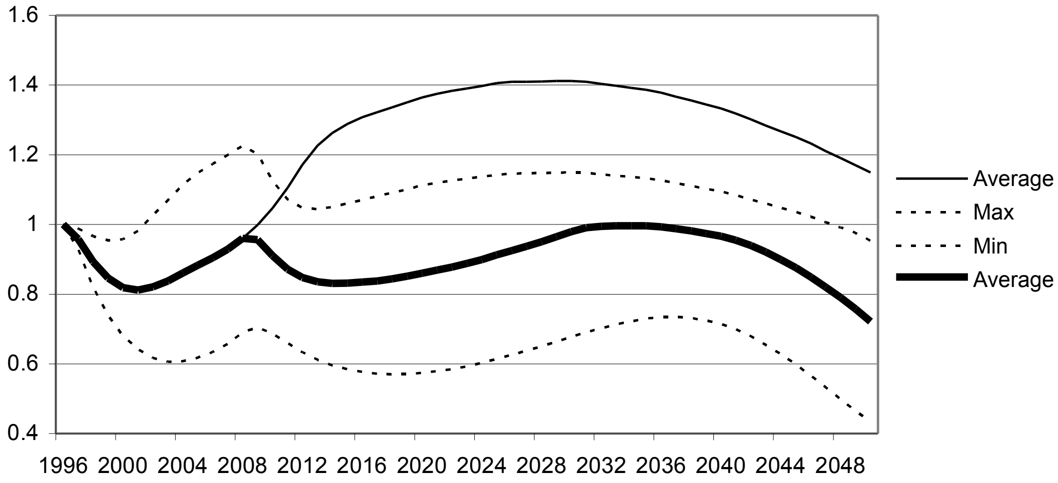

Figure 8 Food prices with fallow land brought into production.

The average food commodities price (without the fallow land been brought into production) is shown with a thin line (as in Figure 6). This is almost 50% higher than the peak average price achieved in the scenario with the fallow land incorporated into total cultivable land. It seems that this should have a considerable effect towards keeping food commodities prices in check. What makes it even more compelling is the timing. As shown in Figure 9, when the same measures were adopted 5 years later, the food prices peaked around 2014. More important though is the fact that after the peak prices remain lower for the period 2020 - 2040.

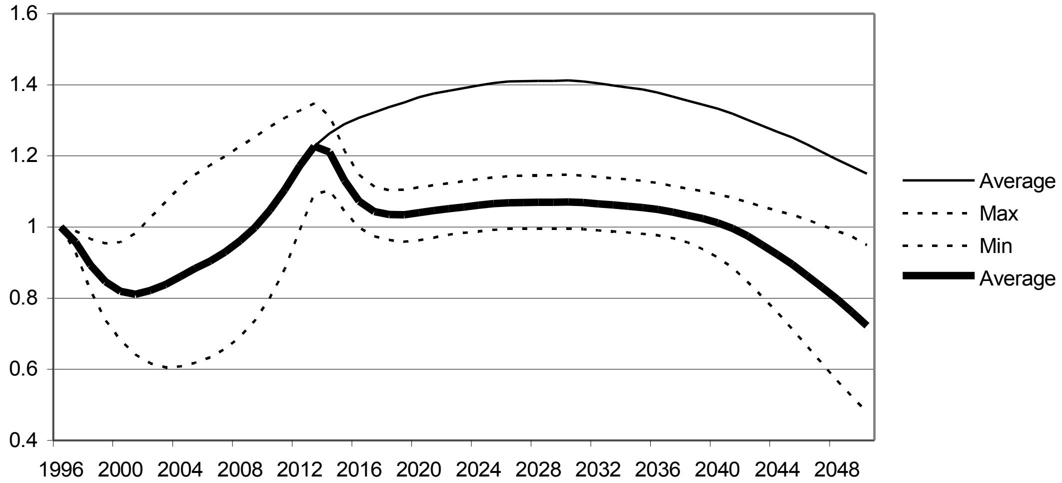

Figure 9 Food prices with fallow land brought into production.

Figure 9 brings into perspective the potential impact that imports from Third World countries can have. These have the potential to lower prices, as in effect it is additional land dedicated to food and biofuel production, but in effect they are akin to 'shifting the burden' (Senge, 1990) to regions outside the EU. These countries are also faced with the situation the model portrays having, with some important differences. For example, the diet of inhabitants is more grain based than protein based and as a result food demand can be covered with less cultivable land. Nevertheless, the cultivable land in each country is finite, and this presents a stark choice: either to stop exports (a valuable source of income) or to import food from abroad. It is plausible that in a highly interconnected world this could ripple like a domino effect, as even the Third World countries that could cope with domestic needs and export grain or biomass, might be faced with increased demand both for food and biomass (Peters and Thielmann, 2008; Banse et al., 2011) and with increased prices for these products from other countries. Clearly, this would make exports financially more attractive, as local markets would shrink, since only a small percentage of the population will be able to respond to even small increases in food commodities prices. This was demonstrated in the case of corn in US and Mexico. An increase in demand for corn in the US due to incentives for bioethanol production fueled tortiya prices in Mexico, despite the fact that half of its cultivable land is used for corn. These phenomena are recurring for an increasing range of agriculture products all around the world (Brown, 2007a; Brown, 2007b), particularly with those products that can be utilized directly in biofuel production. Of course the possibility of cheap imports of agricultural products for countries where people cannot afford anything else but basic food provisions exists. This should abate the domino effect.

But there is an inherent limit here as well, that of agricultural production per se. In these countries usually agricultural cost is already low. Consequently, grain production is nowhere else cheaper than in these places and thus there is nowhere to import cheap grain from. Therefore policies that are designed for the purpose of securing energy supply might not be actually deliver high social or environmental benefits at the countries of implementation, and abroad, without regulating the operation of the entire supply chain (van der Horst, Vermeylen, 2011). This leads to a direction for further research, i.e. to expand and refine the analysis and the model to incorporate explicitly the dynamic between developing and developed countries, involving biomass and grain production and their trade. Such a model would enable a more elaborate study on the global effects of biofuel promotion policies on food supplies.

6. Conclusions

There has been a lot of speculation on the pros and cons of biofuels as an alternative energy source for both industrial and domestic use. Biofuels have been considered as an answer to both energy source scarcity, as well as to controlling CO_2 emissions, especially those of the transportation sector (air, sea, land). Hence they are thought to contribute to a more sustainable transportation sector. However, it seems and is argued accordingly that the benefits from the wide adoption of biofuels, at least at the current stage, do not come without a cost. Concerns on the effect they have on the production of agricultural products for food have been expressed, in some cases they became apparent, thus moderating the initial overstated enthusiasm towards biofuels. In this paper, a systems dynamics approach is applied to explore the issue, the underlying mechanisms, and assess the long term interaction between the biofuels used in transportation and food commodities production and consumption systems, under specific policy implementations.

Overall, simulations of the model have showed that beyond a certain point promoting biomass production for first generation biofuel production is risky on regional (and this would be expected to apply in any region) as far as food availability for low income population is considered. The use of the model showed that policies aimed at restraining the conversion rate at which land, (fallow, already in use, or from deforestation) is put to use for biomass production should be put in place, if food commodities prices are to be kept at reasonable levels. Policies that allow fallow land to be used for any purpose are not effective because they simply result in more land being used for biomass production. As it has been estimated that until 2050 the EU population will stabilize and start to decline (Eurostat, 2008), the pressure on natural resources and population should be eased.

The danger from unconstrained expansion of biofuel production lies in the fact that the EU is not self-sufficient and imports from Third World countries are necessary. Clearly, this is bound to widen the gap between developed and developing countries, if the same policies remain in place. Those that can afford biofuels for their car are already in a financial situation where they can afford food, but it is a different story in Third World countries, where food availability will become a bigger problem with rising prices, a phenomenon already observed in certain countries. This implies that energy policy in the EU is tide to its foreign policy. Under a more distributed and pluralistic governance mode that includes the interests of non governmental organizations for the environment and dealing with humanitarian issues of the Third World, it is expected that EU policies towards biofuels will take into account their effects on the Third World countries because in a highly interconnected world there is 'no such thing as sustainability in one country' (Dresner, 2008, p 90). The situation is exacerbated as most of the 82 low- income countries with food deficits are also net oil importers (Senauer,2008)

As far as the methodological constraints of the study are concerned there are certain limitations worth considering. Oil prices are not incorporated in any way in the model, but they have an effect, on biofuel prices as they have on food. A more thorough investigation of the questions addressed in this article should disaggregate the model into regions

(Gielen, 2003) as they are in EU 15. Including the 12 new member states that have strong agricultural sectors would enable to see whether this would alter the dynamics of the model. An interesting extension would the incorporation of costs that would enable the calculation of the cost of reduction in CO_2 emissions using biofuels and contrasting this with other options.

7. References

Aleklett, K., Hook, M., Jacobsson, K., Lardelli, M., Snowden, S., Soderbergh, B., 2010. The peak of the oil age - analyzing the world oil production reference scenario in world energy outlook 2008. Energy Policy, 38(3), 1398 – 1414

Alexandratos N, de Haen H, 1995. World consumption of cereals: will it double by 2025?. Food Policy. 20: 359 – 366.

Banse M, van Meijl H, Tabeau A, Wolktjer G, Hellman F, Verburg PH, 2011. Impact of EU biofuel policies on world agricultural production and land use. Biomass & Bioenergy, 35, 2385 – 2390

Bartlett A, 2004. The Essential Exponential! For the Future of Our Planet. University of Nebraska Press: Lincoln.

Belcombe K, Rapsomanikis G, 2008. Bayesian estimation and selection of nonlinear vector correction models: the case of the sugar-ethanol-oil nexus in Brazil. Amer J Agr Econ 90: 658-668.

Berndes G, Hoogwijk M, van den Broek R, 2003. The contribution of biomass in the future global energy supply a review of 17 studies. Biomass Bioenergy 25: 1 – 28.

Berndes G, Hansson J, 2007. Bioenergy expansion in the EU: Cost effective climate change mitigation, employment creation and reduced dependency on imported fuels. Energy Policy 35: 5965 – 5979.

Bradsher K, 2008. A new global oil quandary: costly fuel means costly calories. http://www.nytimes.com/2008/01/19/business/worldbusiness/19palmoil.html?em&ex=1200978000&en=0428f9e64240cc22&ei=5087%0A, accessed 16 December 2009

Brown RL, 2007a. Massive diversion of U.S. grain to fuel cars is raising world food prices, risking political instability. Briefing before U.S. Senate Committee on Environment and Public Works, June 13, http://www.earth-policy.org/Transcripts/SenateEPW07.htm. accessed 16 December 2009

Brown RL, 2007b. Will biofuels starve the developing world?. Spiegel, April 27th, http://www.spiegel.de/international/world/0,1518,479940,00.html, accessed 16 December 2010

Charles M B, Ryan R, Ryan N and Oloruntoba R (2007). Public policy and biofuels: the way forward?. Energy Policy 35: 5737 – 5746.

Dresner S, 2008. The Principles of Sustainability. Earthscan: London

European Automobile Manufacturers Association, 2007. Motor vehicles in use. Online industry report. http://www.acea.be/images/uploads/sp/463-4.pdf, accessed 12 December 2009

European Commission, 2000. Monitoring of ACEA (JAMA, KAMA) Commitment on CO2 emission reduction from passenger cars. Brussels COM (643) final staff working paper

European Commission, 2001a. Proposal for a directive of the European parliament and of the council on the promotion of the use of biofuels for transport. Brussels. COM 547.

European Commission, 2001b. Green Paper, Towards a European Strategy for Security of Supply. Directorate-General for Transport and Energy, Brussels http://ec.europa.eu/energy/green-paper-energy-supply/doc/green_ paper_ energy_ supply_en.pdf, accessed 16 December 2009

European Commission, 2001c. Monitoring of ACEA (JAMA, KAMA) Commitment on CO2 emission reduction from passenger cars. Brussels COM (643) final staff working paper

European Commission 2002. Monitoring of ACEA (JAMA, KAMA) Commitment on CO2 emission reduction from passenger cars. Brussels COM (643) final staff working paper

European Commission, 2003. Monitoring of ACEA (JAMA, KAMA) Commitment on CO2 emission reduction from passenger cars. Brussels COM (643) final staff working paper

European Commission, 2004. Monitoring of ACEA (JAMA, KAMA) Commitment on CO2 emission reduction from passenger cars. Brussels COM (643) final staff working paper

European Commission, 2006a. An EU strategy for biofuels. COM 34.

European Commission, 2006b. Implementing the Community Strategy to reduce CO_2 emissions from cars: Sixth annual communication on the effectiveness of the strategy. Communication from the Commission to the council and the European Parliament, COM 463

European Commission, 2007. Cereals: Council approves zero set-aside rate for autumn 2007 and spring 2008 sowings. Brussels, press release IP/07/1402

Eurostat, 2007a. Panorama of energy: energy statistics of support EU policies and solutions. Office for official publications of the European Communities: Luxemburg

Eurostat, 2007b. Passenger cars per 1000 inhabitants. http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,39140985&_dad=portal&_schema=PORTAL&screen=detailref&language=en&product=Yearlies_new_transport&root=Yearlies_new_transport/G/eba12048, accessed 16 December 2009

Eurostat, 2008. Population and social conditions, http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,45323734&_dad=portal&_schema=PORTAL&screen=welcomeref&open=/C/C1/C11&language=en&product=Yearlies_new_population&root=Yearlies_new_population&scrollto=0, accessed 16 December 2009

European Commission, 2010. EU energy and transport in figures: statistical pocket book. Publications Office of the European Union: Luxemburg

Fischer G, 2009. World food and agriculture to 2030/50: how do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?. ftp://ftp.fao.org/docrep/fao/012/ak969e/ak969e00.pdf, accessed 12 December 2009

Fonseca MB, Burrell A, Gay H, Henseler M, Kavallari A, M'Barek R, Dominguez IP, Tonini A, 2010. Impacts of the EU biofuel tqrget on agricutlural markts and land use: A comparative modelling assessment. Institute for Prospective Technological Studies report EUR 24449

Geels FW, 2004. From sectoral systems of innovation to socio technical systems: insights about dynamics and change from sociology and institutional theory. Res Policy 33: 897 – 920.

Gerbens – Leens PW, Nonhebel S, 2002. Consumption patterns and their effects on land required for food. Ecol Econ 42: 185 – 199.

Gielen D, Fujino J, Hashimoto S, Moriguchi Y, 2003. Modeling of global biomass policies. Biomass Bioenergy 25: 177 – 195.

Gillard B, 2002. World population and food supply: can food production keep pace with population growth in the next half century?. Food Policy 27: 47 – 63.

Hall DO, House JI, 1995. Biomass energy in Western Europe to 2050. Land Use Policy 12: 36 – 48.

Hoogwijk M, Faaij A, van den Broek R, Berndes G, Gielen D, Turkenburg W, 2003. Exploration of the ranges of the global potential of biomass for energy. Biomass Bioenergy 25: 119 – 133.

Hoogwijk M, Faaij A, Eickhout B, de Vries B, Turkenburg W, 2005. Potential of biomass energy out to 2100, for four IPCC SRES land use scenarios. Biomass Bioenergy 29: 225 – 257.

van der Horst D, Vermeylen S, 2011. Spatial scale and social impacts of biofuel production. Biomass & Bioenergy, 35, 2435 – 2443

Ignaciuk A, Vohringer F, Ruijs A, van Ierland EC, 2006. Competition between biomass and food production in the presence of energy policies: a partial equilibrium analysis. Energy Policy 34: 1127 – 1138

International Energy Agency, 2004. Biofuels for transport: An international perspective. Paris.

Intergovernmental Panel on Climate Change, 2007. Parry M L, Canziani O F, Palutikof J P, van der Linden P J and Hanson C E (eds). Contribution of Working Group II to the Fourth Assessment Report. Cambridge University Press: Cambridge.

Janssen R., Rutz D., 2007, Biofuel technology handbook, WIP Renewable Energies

Kern F, Smith A, 2008. Restructuring energy systems for sustainability? Energy transition policy in the Netherlands, Energy Policy 36: 4093 – 4103

Lotze – Campen H, Muller C, Bondeau A, Lucht W, 2005. How tight are the limits to land and water use? combined impacts of food demand and climate change. Adv. Geosciences 4: 23-28.

McCormick K, Kaberger T, 2007. Key barriers for bioenergy in Europe: Economic conditions, know how and institutional capacity and supply chain coordination. Biomass Bioenergy 31: 443 – 452.

Meadows DH, Randers J, Meadows DL, 2004. Limits to growth – The 30 year update. Chelsea Green: Vermont.

Meza CMC, Dijkema JPG, 2009. Transition to renewable energy sources some lessons of the Brazilian case, International Studies Association, 48th annual convention, New York, US.

Mingers J, 2004. Future directions in management science modeling: critical realism and multimethodology. In: Fleedwood S and Ackroyd S (eds.) Critical Realist Applications in Organisation and Management Science. Routledge: London, pp 164 - 193.

Mingers J, 2006. Realising Systems Thinking: Knowledge and Action in Management Science. Springer: New York.

Nazlioglu S, 2011. World oil and agricultural commodity prices: Evidence from non linear causality. Energy Policy, 39, 2935 – 2943

Parry M L, Rozenzeig C, Iglesias A, Livermore M, Fischer G, 2004. Effects of climate change on global food production under SRES emissions and socio economic scenarios. Global Environ Chang 14: 53 – 67.

Peters J, Thielmann S, 2008. Promoting biofuels: Implications for developing countries. Energy Policy 36: 1538 – 1544.

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Marten Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.L., Victoria J.F., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A., 2009. A safe operating space for humanity. Nature, 461, 472 – 475

Ryan L, Convery F, Ferreira S, 2006. Stimulating the use of biofuels in the European Union: implications for climate change policy. Energy Policy 34: 3184 – 3194.

Sandvik S, Moxnes E, 2009. Peak oil, biofuels and long term food security. Proceedings of the 29th International System Dynamics Conference, Albuquerque, NM, USA

Schade B, Wiesenthal T, 2011. Biofuels: A model based assessment under uncertainty applying the Monte Carlo method. Journal of Policy Modelling, 33, 92 – 126

Senge P, 1990. The Fifth Discipline: the art and practice of the learning organization. Doubleday: New York.

Senauer, B., 2008. Food market effects of a global shift toward bioenergy. American Journal of Agricultural Economics, 90, 1226 - 1232

Sorensen B (2007). A sustainable energy future: Construction of demand and renewable energy supply scenarios. Int J Energ Res 32: 436-470.

Steenberghen T, Lopez E, 2008. Overcoming barriers to the implementation of alternative fuels for road transport in Europe. J Clean Prod 16: 577 – 590.

Timilsina GR, Shrestha A, 2011. How much hope should we have for biofuels?. Energy, 36, 2055 – 2069

Tzimas E, Soria A, Peteves SD, 2004. The introduction of alternative fuels in the European transport sector: Techno economic barriers and perspectives. IPTS technical Report Series.

United Nations, 2006. The 2006 Revision Population Database. http://esa.un/unpp, accessed 12 December 2009.

Umbach, F., 2010. Global energy security and the implications for the EU. Energy Policy, 38(3), 1229 – 1240

Unruh GC, 2000. Understanding carbon lock-in. Energy Policy 30: 317 – 325.

Witze A, 2007. That's oil folks. Nature 445: 14.

Witzke P, Banse M, Gomann H, Heckelei T, Breuer T, Mann S, Makrus K, Adenauer M, Zintl A, 2008. Modelling of energy crops in agricultural sector models, Institute for Prospective Technological Studies. http://ftp.jrc.es/EURdoc/JRC42597.pdf, accessed 12 December 2009.

Wright L, 2006. Worldwide commercial development of bioenergy with a focus on energy crop based projects. Biomass Bioenergy 30: 706 – 714.

Wolf J, Bindraban PS, Luijten JC, Vleeshouwers LM, 2003. Exploratory study on the land area required for global food supply and the potential global production of bioenergy. Agr Syst 76: 841 – 861.

Zhang Z, Lohr L, Escalante C, Wetzstein M, 2010. Food versus fuel: What do prices tell us. Energy Policy 38: 445 – 451.