ASSESSMENT OF DIFFERENT BIOFUEL SUPPORT POLICIES CONSIDERING UNCERTAINTIES OF KEY PARAMETERS

Burkhard Schade[1], European Commission, JRC-IPTS, Edificio Expo; C/ Inca Garcilaso, s/n; E-41092 Sevilla, Spain, tel: + 34 95 4488475; fax: + 34 95 4488279; burkhard.schade@ec.europa.eu
Tobias Wiesenthal[1], European Commission, JRC-IPTS, Edificio Expo; C/ Inca Garcilaso, s/n; E-41092 Sevilla, Spain, tel: + 34 95 4488306; fax: + 34 95 4488279; wiesenthal.tobias@ec.europa.eu

Theme: F4, F6 or E3.

ABSTRACT

The aim of this paper is to assess different biofuel support policies with the model BioPOL. The development of the biofuel production depends highly on a set of input parameters which are inherently uncertain. Therefore, we set the focus in this analysis specifically on the way we deal with this uncertainty.

BioPOL was developed and applied within the several European projects, among them TRIAS, PREMIA, HOP. BioPOL model is a system dynamic model that is constructed on the VENSIM modelling platform. It is based on a recursive year by year simulation of biofuel demand and supply until 2030. For each set of exogenously given parameters a level of biofuel production is found at which the costs of biofuels equal those of the fossil alternative they substitute, taking into account the feedback loops of the agricultural market and restrictions in the annual growth rates of capacity.

The model delivers detailed outcomes for the different types of biofuels with regard to production capacity and produced volumes, costs and well-to-wheel emissions of greenhouse gases. It considers the main production pathways of biofuels, namely first generation biodiesel with rapeseed and sunflower and first generation ethanol with cereals and sugar beet. Furthermore, it includes advanced 2nd generation pathways from ligno-cellulosic feedstock (i.e. ethanol and synthetic diesel BtL).

The deployment of biofuels in the transport market depends on a variety of factors, some of which are inherently uncertain such as the outlook on the oil and feedstock prices or trends in advanced biofuel conversion technologies. These uncertainties will need to be taken into account when conducting a model-based assessment of the effectiveness of future biofuel policies. In this paper, the response of the model, which simulates the deployment of various types of biofuels, to the variance of input parameters is analysed. The most relevant input parameters are then modified simultaneously using the Monte Carlo simulation method. On this basis, the expected opportunity losses are being calculated for two policy cases. This approach proves useful for evaluating the risks related to distinct policy options despite of the prevalence of important uncertainties.

The work undertaken demonstrates the importance of dealing with the uncertainties related to relevant import parameters. These parameters include the oil price, the learning effect of 2nd generation biofuels and associated cost decrease of advanced biofuel production technologies, the feedback of rising biofuel feedstock on feedstock prices, and the share of imports. For example, it needs to be taken into consideration that soaring oil prices affect the biofuel production in two opposite ways. On one hand, they foster the substitution of oil by biofuels. On the other hand, as oil is an important input in the biofuel production high oil prices lead to an increase of production costs on biofuels.

---

[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission

TABLE OF CONTENTS

1. INTRODUCTION

Biofuels have gained in political momentum in recent years. In the European Union, the biofuels directive sets an indicative target of a 5.75% share of biofuels in total gasoline and diesel demand to be met by 2010. By 2020, EU Member States shall ensure that the share of renewable sources (including biofuels) in all forms of transport is at least 10% of the final energy consumption in transport.

In order to achieve the targets set by the biofuel directive, Member States have set national objectives and introduced diverse biofuel support policies [see e.g. Wiesenthal et al., 2009; Di Lucia and Nilsson, 2007[i]]. These measures range from tax reductions, which is allowed for under [DIR, 2003b], to quotas prescribing a minimum biofuel share. Furthermore, premiums for energy crops were introduced to support the cultivation of bioenergy feedstock [REG, 2003; EC, 2006b] and the cultivation of non-food crops on set-aside areas has been allowed up to a certain amount [BHA, 1992].

As a consequence, consumption of biofuels increased substantially in the EU over the past decade to reach a share of 1.8% in the final consumption of gasoline and diesel in 2006 [DG TREN 2009] and an estimated share of 2.7% by 2007 [EurObserv'ER, 2009].

The aggregated production volumes of biodiesel and bioethanol in EU Member States grew by a factor of 4.5 and 3.1 between 2000 and 2005, with biodiesel remaining the dominant biofuel in the European with 81.5% of total biofuel volumes. Also on a global scale, the EU is by far leading the biodiesel market, while the European share in bioethanol is limited compared with Brazil and the USA.

Despite the fast uptake in recent years, the share of biofuels remains well below those of the 2010 target and the aspiration for 2020. It is thus of interest to assess how the targets can (best) be reached. For this purpose, diverse economic models have been applied over the past years to assess those drivers (REFUEL, GREENx, PRIMES, TIMES, see res2020).

One of the main criteria for the deployment of biofuels is the trend assumed for future oil prices, as this largely determines the relative competitiveness between biofuels and their fossil substitute. The rapid increase of feedstock prices in 2007/8 with a sharp decline afterwards demonstrated the uncertainties related with the biofuel production costs. At the same time, high uncertainties are associated with the trends in performance and costs of advanced biofuels that shall overcome many of the drawbacks of conventional first generation biofuels (REF).

The aim of this paper is to assess different biofuel support policies with the model BioPOL. The development of the biofuel production depends highly on a set of input parameters which are inherently uncertain. Therefore, we set the focus in this analysis specifically on the way we deal with this uncertainty.

BioPOL was developed and applied within the several European projects, among them TRIAS, PREMIA, HOP. BioPOL model is a system dynamic model that is constructed on the VENSIM modelling platform. It is based on a recursive year by year simulation of biofuel demand and supply until 2030. For each set of exogenously given parameters a level of biofuel production is found at which the costs of biofuels equal those of the fossil alternative they substitute, taking into account the feedback loops of the agricultural market and restrictions in the annual growth rates of capacity.

The model delivers detailed outcomes for the different types of biofuels with regard to production capacity and produced volumes, costs and well-to-wheel emissions of greenhouse gases. It considers the main production pathways of biofuels, namely first generation biodiesel with rapeseed and sunflower and first generation ethanol with cereals and sugar beet. Furthermore, it includes advanced 2nd generation pathways from ligno-cellulosic feedstock (i.e. ethanol and synthetic diesel BtL).

The deployment of biofuels in the transport market depends on a variety of factors, some of which are inherently uncertain such as the outlook on the oil and feedstock prices or trends in advanced biofuel conversion technologies. These uncertainties will need to be taken into account when conducting a model-based assessment of the effectiveness of future biofuel policies. In this paper, the response of the model, which simulates the deployment of various types of biofuels, to the variance of input parameters is analysed. The most relevant input parameters are then modified simultaneously using the Monte Carlo simulation method. The work undertaken demonstrates the importance of dealing with the uncertainties related to relevant import parameters. These parameters include the oil price, the learning effect of 2nd generation biofuels and associated cost decrease of advanced biofuel production technologies, the feedback of rising biofuel feedstock on feedstock prices, and the share of imports

On this basis a number of policy scenarios are compared. For each policy scenario a Monte Carlo simulation is carried out. The expected opportunity losses are being calculated for several policy scenarios. Finally, in case the assessment of two policy scenarios is very close an analysis on the scenario conditions is undertaken. This approach proves useful for evaluating the risks related to distinct policy options despite of the prevalence of important uncertainties.

2. MODEL AND POLICIES

2.1. Model description

2.1.1. The Biofuels Model

The biofuel model is based on a recursive year by year simulation of biofuel demand and supply until 2050. For each set of exogenously given parameters an equilibrium point is calculated at which the costs of biofuels equal those of the fossil alternative they substitute, taking into account the feedback loops of the agricultural market and restrictions in the annual growth rates of capacity. This equilibrium point is envisaged by market participants but not necessarily reached in each year.

Increasing production of biofuels and a subsequent rise in feedstock demand has an impact on the prices of biofuel feedstock, which in turn affects biofuel production through a feedback loop (Figure 1).

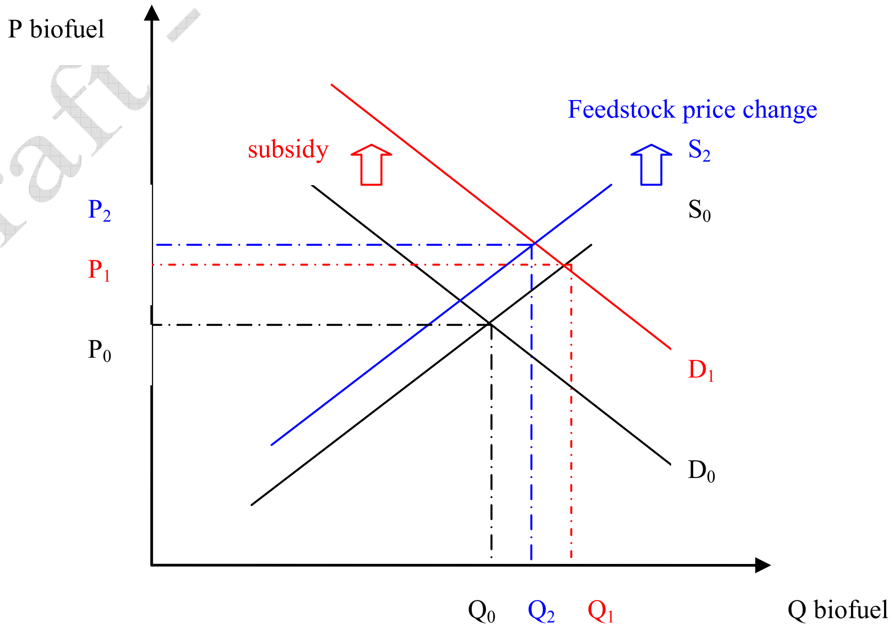

Figure 1: Biofuel supply and demand shifts

First, the equilibrium point for the consumption of biofuels is identified. Keeping the other factors constant, this would correspond to an equilibrium price for feedstock from each pathway. At that level, a certain amount of feedstock would be produced as a result of the agricultural market increasing or decreasing its supply compared to the reference case. The change in the supply of biofuel feedstock will affect the area of cultivated land for these feedstocks, the area for other products, as well as imports and exports of all related agricultural products. As a result, prices will change and strongly influence the costs of biofuel production as feedstock prices account for between around two thirds up to around 90% of total production costs for conventional biofuels.

The reaction of the agricultural markets thus influences the production costs of biofuels and, subsequently, the level of biofuel supply as shown schematically in Figure 1. This feedback is modelled through a number of econometrically estimated equations, which are based on information in the ESIM model simulation results and DG Agriculture.

It needs to be noted that the resource limits are exclusively taken into account through the price effects, while upper physical limits for domestic biofuel feedstock supply were not considered. These necessitate a value judgement regarding e.g. the extent to which farmland with a high nature value can be used for bioenergy cropping and whether food/fodder crop cultivation shall be given higher priority than bioenergy production. The model delivers detailed outcomes for the types of biofuels considered – biodiesel or ethanol, first or second generation – with regard to production capacity and produced volumes, costs and well-to-wheel emissions of greenhouse gases. Historical values for biofuel production, consumption and production capacities are incorporated up to 2005.

The model focuses on the main production pathways of biofuels, namely biodiesel based on rapeseed and sunflower and ethanol based on wheat and sugar beet, as well as advanced 2nd generation pathways from lignocellulosic feedstock (i.e. ethanol and synthetic diesel BtL). For the 1st and the 2nd generation of biofuels the technical coefficients, costs and greenhouse gas emissions are based on the analysis carried out by the JEC study [JRC/EUCAR/CONCAWE, 2006].

Figure 2 summarises the way the different factors interact. Impacts are traced in the various sectors. The chart is restricted to the EU domestic biofuel market. Regarding imports, biofuel prices are given as exogenous variables as well as their maximum penetration levels. Other main exogenous parameters include

- Selection of biofuel production pathways;
- Production costs and maturity factors (learning of new production technologies);
- Well-to-wheel emissions of greenhouse gases;
- Development of oil prices and subsequently the fossil fuel prices;
- Elasticities of the raw material prices;
- Transport fuel demand.

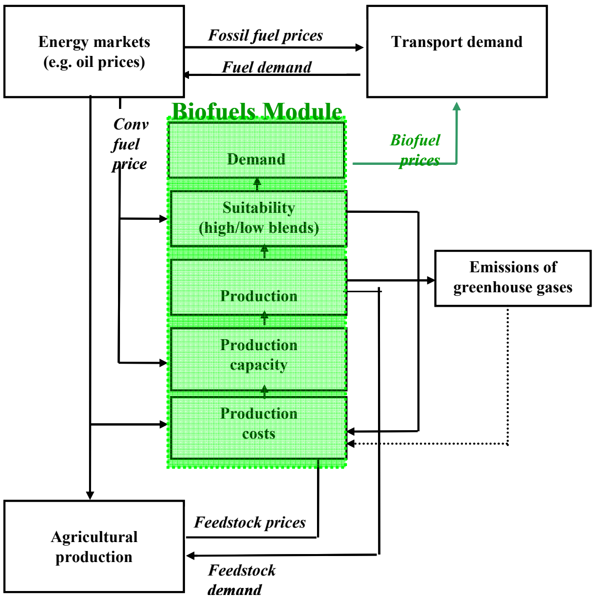

Figure 2: Interaction of factors affecting supply and demand of biofuels

The model determines the penetration of biofuels as a function of final price of biofuels relative to the pump price of fossil fuels. These are affected by the prices of oil and raw materials as well as the production costs that each alternative pathway entails (depending on capital costs, feedstock prices, load factors etc.)

The relation of biofuel production costs to fossil prices excluding taxes is considered as an incentive for investors to install additional production capacities, which in return leads to an increased amount of biofuels produced. The additional installed capacity per year depends on the distance to the equilibrium point (and thus the profit margin) and starts from historical values: the average annual growth rate of biodiesel and bioethanol capacity was about 44% and 69% over the period 2002 to 2006, respectively, and prospects for currently planned projects indicate that similar rates are likely to continue also for the coming two years.

The main factors that determine the equilibrium point via influencing the cost ratio of biofuels and fossil fuels are oil prices, distribution costs and feedstock prices:
Oil prices influence the level of biofuel deployment as they are directly linked to fossil fuel prices. On the other hand, they influence biofuel production costs for which energy costs account for up to 15%. Besides, there is a limited, yet not negligible impact of oil prices on the feedstock costs, which is taken from the JEC study [JRC/EUCAR/CONCAWE, 2006].

Once the biofuel penetration exceeds a certain share and passes from low blends to higher blends or pure biofuels, additional costs occur due to distribution and blending and potentially adaptation of car engines.

Increasing production of biofuels and a subsequent rise in feedstock demand has an impact on the prices of biofuel feedstock, which in turn affects biofuel production through a feedback loop. First, the equilibrium point for the consumption of biofuels is identified. Keeping the other factors constant, this would correspond to an equilibrium price for feedstocks from each pathway. At that level, a certain amount of feedstock would be produced as a result of the agricultural market increasing or decreasing its supply compared to the reference case. The change in the supply of biofuel feedstock will affect the area of cultivated land for these feedstocks, the area for other products, as well as imports and exports of all related agricultural products. As a result, prices will change and strongly influence the costs of biofuel production as feedstock prices account for between around two thirds up to around 90% of total production costs for conventional biofuels. The reaction of the agricultural markets consequently influences the production costs of biofuels and, subsequently, the level of biofuel supply and demand.

This feedback is modelled through a number of econometrically estimated equations, which are based on information in the ESIM model simulation results for the agricultural sector and DG Agriculture. It needs to be noted that the resource limits are exclusively taken into account through the price effects, while upper physical limits were not considered.

In a first step, the model calculates the production cost *'cbf_b'* per unit of tonne of oil equivalent (toe) for each type of domestically produced biofuel. cbf_b depends on capital costs, fixed operational costs, energy costs and feedstock minus the price obtained for by-products. The way how the production cost and its components are derived is shown in the following equations:

$$cbf_b = cap_b + opf_b + ope_b + fsb_b - crd_b \tag{1}$$

$$cap_{b,t} = cap_{b,ref} \cdot (1 - suc_b) \cdot (1 - lrn_{b,t})^{t-t_0} \tag{2}$$

$$opf_{b,t} = opf_b^{ref} \cdot (1 - lrn_{b,t})^{t-t_0} \tag{3}$$

$$ope_{b,t} = ope_b^{ref} \cdot (\frac{oip_t}{oip^{ref}})^{eop} \tag{4}$$

$$fsb_{bg1,t} = \sum (fsc_{cr,t} \cdot shb_{cr}) \tag{5}$$

$$fsc_{cr,t} = fsc_{cr}^{ref} \cdot (1 - suf_b) \cdot (\frac{bfp_{cr,t}}{bfp_{cr}^{ref}})^{ebp} \cdot (\frac{oip_t}{oip^{ref}})^{eof} \tag{6}$$

$$fsb_{bg2,t} = fsb_{bg2}^{ref} \cdot (1 - suf_{bg2}) \cdot (\frac{bfp_{bg2,t}}{bfp_{bg2}^{ref}})^{ebg} \cdot (\frac{oip_t}{oip^{ref}})^{eof} \tag{7}$$

$$crd_{b,t} = shc_{b,t} \cdot cda_b + (1 - shc_{b,t}) \cdot cde_b \tag{8}$$

$$shc_{b,t} = \begin{cases} 0.8, if : bfp_{b,t}^{in+im} <= 5000 \\ 0.2, if : bfp_{b,t}^{in+im} >= 12000 \\ 0.8 - 0.6 \cdot \dfrac{(bfp_{b,t}^{in+im} - 5000)}{(12000 - 5000)}, else \end{cases} \tag{9}$$

With cbf: cost of biofuels per toe
cap: capital cost of biofuels per toe
opf: fixed operational cost of biofuels per toe
ope: costs of the energy input for biofuels per toe
fsb: feedstock cost of biofuels per toe
crd: credits cost of biofuels per toe
suc: capital subsidy as percentage
lrn: learning rate for biofuel production
eop: elasticity oil price on production cost (energy input per unit)
oip: oil price
fsb: feedstock cost of biofuels per toe
fsc: feedstock cost of crops per toe
shb: share of crop in a certain type of biofuel
suf: feedstock subsidy as percentage
bfp: biofuel production per toe
ebp: elasticity biofuel production first generation on feedstock cost
eof: elasticity oil price on feedstock cost
ebg: elasticity of biofuel production second generation on feedstock cost
crd: credits of biofuels per toe
shc: share of biofuels were credits can be gained from animal feed
cde: credits for energy use
cda: credits for animal feed

As can be seen from equation (2) and (3) the effects of reduction of **fixed costs** (i.e. capital costs 'cap_b' and fixed operational costs per toe 'opf_b') through technological learning are accounted for. Learning rates are not endogenous as the model focuses on the EU region only. Instead, a certain cost reduction is assumed for the year 2030, which is then translated into a learning rate. In addition, the model can also simulate the effect of an investment subsidy 'suc_b' granted on the capital costs by simply deducting it from the initial capital cost.

With respect to **variable costs** of biofuel production, the model considers three main impacts:

Firstly, the oil price '*oip*' affects biofuel production costs for which energy costs '*ope*' account for up to 15%. This is shown in equation (4).

Secondly, and most importantly, the variable costs depend on the feedstock costs '*fsc*'. Indeed, for first generation biofuels, feedstock costs can make up between 60% and 90% of total production costs, while their contribution is in the order of some 30%-40% for 2nd generation biofuels. Hence, an increase in the production of biofuels and the related rise in feedstock demand has an impact on the prices of the biofuel feedstock, which in turn affects biofuel production through a feedback loop. This is simulated through price-demand elasticities per type of feedstock. For first generation biofuels, these elasticities are derived from elasticities for relevant crops and multiplied with the share of the feedstock used for biofuel production. For second generation biofuels, two distinct elasticities are used, depending on the cumulative production volumes. Up to a production volume of around 3.5 Mtoe and 6 Mtoe[2] of ligno-cellulosic ethanol and Fischer-Tropsch biodiesel, respectively, it is assumed that most of the feedstock comes from by-products such as straw or wood waste/residues with comparably high price-demand elasticities (0.65 and 0.35) which reflects the price jump between feedstock from by-products and farmed wood. With higher production, the primary origin of feedstock changes to dedicated energy crops, and the resulting elasticities are larger (0.79 and 0.47), reflecting the fact that biofuel production is the main user of the energy crops cultivated. The impact of changes in the oil prices on the feedstock costs is also considered. At the same time, the model allows to simulate a subsidy on the feedstock costs, such as the energy crop scheme. The resulting feedstock prices are shown in equations (5) and (6) for first generation biofuels and in equation (7) for second generation biofuels, respectively.

Note that for imported biofuels, no production costs are being calculated as it is reasonable to assume that imported biofuels will not be sold at the production costs in the EU. This is due both to import duties of the WTO (protecting the domestic market) and a motivation of producers to sell their biofuels at the highest price possible, thus equaling the lowest price of domestically produced biofuels. For that reason, one could estimate for imported biofuel to take the lower end of the EU domestic biofuel market prices. We assumed some strategic pricing so that the costs of imports are slightly (5%) below that of domestically produced biofuels. The resulting volumes of biofuels that are imported into the EU at that price are determined based on cost-supply curves, which are taken from Resch et al. (2009).

Thirdly, the price obtained for by-products (credits '*crd*') need to be considered in the net biofuel production costs. The way in which by-products are used (e.g. as chemical or animal feed; as energy use or feed) can have a significant impact on the net costs as well as on the specific emissions of greenhouse gases. In order to not over-estimate the benefits and be more realistic vis-à-vis a saturation of by-product markets, it is assumed that in the case of glycerine from biodiesel production by-products will be used for animal feed rather than as chemical substitute. DDGS (distiller's dried grains with solubles) from ethanol production will primarily be used as animal feed (80% of total volume) until production levels reach around 5000 toe. With increasing production volumes, the energetic use

---

[2] These values are derived from the potential of suitable woody and herbaceous residues in the EU-28 countries in the year 2020 calculated in Thrän et al. (2007). It has been assumed that about half of the potential can be made available for BtL and ethanol production, while the other half either serves for other purposes or cannot be collected at a reasonable price. The relation to biomass input (in MJ) to fuel output (in MJ) has been assumed to be 2.4 for lingo-cellulosic ethanol from straw and 2.6 for BtL based on JEC(2007).

of DDGS increases up to a share of 80% of all by-products at production levels of 12000 toe (equations (8) and (9)).

In a second step, the model calculates an equilibrium point for the penetration of biofuels as a function of final price of biofuels relative to the pump price of fossil fuels. It first determines the final market price of biofuels (per litre) based on the production costs *'cbf'* (see above equation 1), the prices of imported biofuels and the applicable tax *'tbf'*. Furthermore, once the biofuel penetration exceeds a certain share and passes from low blends to higher blends or pure biofuels, additional costs occur due to distribution and blending and potentially adaptation of car engines. This is included through a proxy *'xbf'*.

$$bfp_{b,t} = ((bfw \cdot bfc_{b,t}) + ((1-bfw) \cdot bfc_{b,t-1})) \cdot bur_b \cdot uet_b \tag{10}$$

$$bfc_{b,t+1} = bfc_{b,t} + \Delta bfc_b \tag{11}$$

$$\Delta bfc_b = Min(Max(bfi_b, -mdc \cdot bfc_b), mcg \cdot bfc_b)) \tag{12}$$

$$bfi_b = \frac{(\frac{pff_b}{pbf_b} - 1)}{ebg} \tag{13}$$

$$pbf_b = (\frac{cbf_b}{lpt_b} + tbf_b + xbf_b) \tag{14}$$

With pbf: market price of biofuels per liter
cbf: cost of biofuels per toe
tbf: tax of biofuels per liter
xbf: extra cost (like cost for adaption of vehicles) of biofuels per liter
lpt: conversion of toe into liter
bfi: incentive for increasing biofuel capacities
pff: market price of fossil fuels per liter
pbf: market price of biofuels per liter
ebg: elasticity of biofuel production second generation on feedstock cost
ibf: investment in biofuel production capacity per biofuel type
bfp: biofuel production per biofuel type
bfc: production capacity of biofuel per biofuel type
mdc: maximal depreciation of capital
mcg: maximal growth of capital
bfc: production capacity of biofuel per biofuel type
bfw: weight of current capacity and the capacity of the previous year
bur: biofuel utilisation rate
uet: unit converter energy in toe per ton of biofuels

The relation of biofuel prices to fossil prices is then considered as an incentive for investors to produce additional amounts of biofuels, the level of which depends on the distance to the equilibrium point and thus the profit margin (equation (13)). Furthermore, the impact of the increased biofuel production volumes on the costs of biofuels is taken into account through the price-demand elasticity of feedstock.

As a consequence of the need for additional biofuel production, there will be investments in the construction of additional production capacities for the different biofuel types; a cap *'mcg'* is set on the production capacities that can be added in a year (equation (12)): the average annual growth rate of biodiesel and bioethanol capacity was about 44% and 69%, respectively, over the period 2002 to 2006. From this we derive an upper limit for the increment of capacity in a single year of maximal 80%, which seems to be at the rather high side and thus mainly serves as a 'safety barrier'.

At a certain point in time, the total amount of biofuels produced is described by equation (12), based on the existing and newly installed production capacities and a rate of utilisation *'bur'*. Keeping the other factors constant, the trend in the annual biofuel production converge towards the equilibrium point where the final price of biofuels equals that of the fossil substitutes. This equilibrium point will, however, never be actually attained due to a number of feedback loops such as the changes in feedstock prices or the additional costs that occur from the adaptation of the engine once the penetration of biofuels reaches a certain amount (see above).[3]

In a third step, the model derives a number of output variables from the domestic production volume per biofuel and the consumption of imported biofuels. These include the share of biofuels in transport gasoline and/or diesel demand, the additional costs of biofuels when compared to fossil fuels and the greenhouse gas emissions avoided through the substitution of fossil fuels.

The BioPOL model depends on a number of exogenous parameters. In order to ensure consistency between inherently interlinked parameters such as the production processes and emissions that are specific for every biofuel production pathway and are sensitive to the way of accounting for e.g. by-products, an effort has been made to stay close to a limited number of studies only. Here, the Well-to-Wheel Analysis from JEC [JRC/EUCAR/CONCAWE, 2007, 2008] was chosen as a reference work.

Furthermore, a link to the global energy model POLES was created, which is being used to import the closely linked parameters oil price, and via the fossil fuel prices the transport demand [described in Schade et al., 2007]. Moreover, the (soft) coupling with the POLES model could also be used to account for the effects of increased biofuel consumption on the oil price and related modifications in transport demand. For the present paper, however, the latter is not used as it would have significantly increased the running time needed for the ten thousand Monte Carlo simulations.

2.2. Reference Scenario

To enable to compare a set of biofuel policies the development of a reference scenario is necessary. The reference scenario doesn't contain any biofuel supporting policies. Fossil fuel pries, the oil price, and the road transport fuel consumption stem from POLES. Within the time period of the references scenario an oil price of 80 € is considered. Even though fossil fuel prices have been decreasing since their peak at about 150$/bbl in 2008, supported by the global economic downturn, rising demand from fast developing regions and uncertainty about the future availability of cheap resources are suggesting that crude oil prices will not fall back to the low levels observed before 2007. It is therefore assumed that they rise from present prices and then remain at high levels at around 80 €/bbl. Fuel taxes are expect to remain stable in constant prices, while a special carbon tax is introduced and, therefore, a carbon tax is included in the price for fossil transport fuels. A carbon price of 60 €/t $CO_{2\text{-equivalent}}$ is assumed for 2030. This value lies some 5€/t $CO_{2\text{-equivalent}}$ below the carbon price calculated for a 2 degree mitigation scenario throughout all industrialised world regions and sectors by 2030 (Russ et al., 2007).

The biofuel consumption is expected to increase over time reaching a share of 8.3% in 2020. It has to be mentioned that the share of biofuels refers to of consumption of biofuels to fuel consumption in road transport. Air, maritime and rail transport is not considered.

From the beginning until 2015 biodiesel is expected to have the highest share in biofuel consumption, while bioethanol is becoming the dominant biofuel afterwards. 2nd generation biofuels enter the market much later. Ligno-cellulosic is entering the market around 2017, while BTL is entering the market in 2025.

---

[3] Note that the model can also simulate the existence of a quota that prescribes the biofuel share for a certain target year. In that case, the model first calculates the consumption volumes of biofuels needed in a certain year, and then distributes these among the various biofuel production pathways and imports depending on their relative costs (and additional policy restrictions, if introduced).

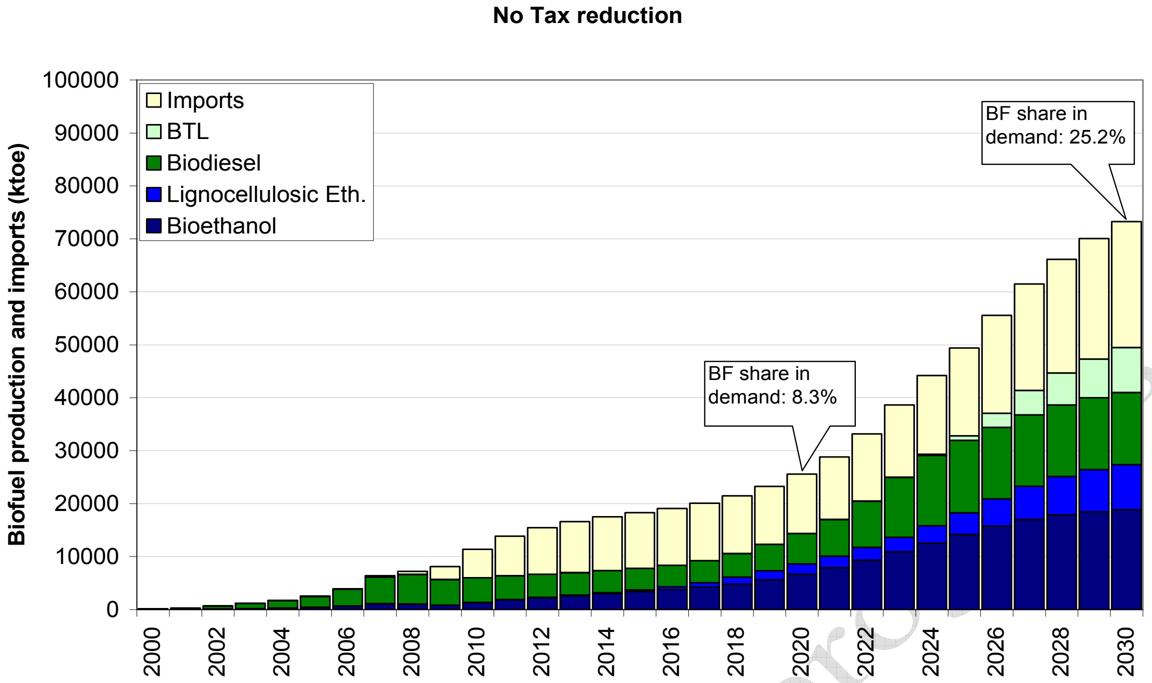

Figure 3: Development of inland biofuel production and imports over time assuming no policies from fossil fuel tax (and an oil price of 80 EUR/bbl) [Schade, 2010]

2.3. Biofuel support policies

Meeting the biofuel targets most likely implies for a future biofuel support policy that needs to be at the same efficient. Within this paper, a number of instruments are being analysed and compared with a reference scenario where no policy instruments are implemented. All discussed policy instruments are hypothetical. However, some countries already gained experience with a set of policy instruments (see for an overview [Wiesenthal, 2007, 2009]).

A large variety of biofuel support policies are in place in EU Member States, ranging from command and control instruments such as standards and quotas, over economic and fiscal measures, such as tax exemptions, to information diffusion. Furthermore, they address different stages of the biofuel chain, i.e. covering R&D for new technologies as well as market diffusion.

As (conventional) biofuels are a mature fuel, the policy focus today often lies on facilitating their market entry rather than R&D support. This implies that market demand is created by policies, as the production costs of biofuels lie above those of fossil fuels (unless very high oil and/or carbon dioxide emission prices are attained). This can be done through basically two instruments: subsidization or prescription of a mandatory production.

Under the first scheme, biofuels are subsidized so as to reduce the price level to that of fossil fuels (or below). The second approach consists of prescribing a fixed quantity of biofuels to be supplied by fuel suppliers on an obligatory basis.

Referring to the first option we discuss experiences with tax exemption schemes, which has proven successful although it caused important revenue losses for government. Furthermore, capital grants and feedstock subsidies are described as well.

In the second option, fuel suppliers are obliged to achieve a certain biofuel share in their total sales. Here, fuel suppliers and ultimately the transport users will carry the additional costs. Additionally, quotas are discussed when 2nd generation of biofuels count double.

2.3.1. Tax reductions

The EU Energy Taxation Directive [EU, 2003c] sets the framework for this instrument for Member States by allowing exempting biofuels from taxes under the conditions that:

- The tax exemption or reduction must not exceed the amount of taxation payable on the volume of renewables used;
- Changes in the feedstock prices are accounted for in order to avoid overcompensation;
- The exemption or reduction authorised may not be applied for a period of more than six consecutive years, renewable.

Past experience shows that partial or total exemptions from fuel taxes for biofuels were vital in promoting biofuels in the EU. All Member States with a high penetration of biofuels have, or have had, a favourable tax regime in place, e.g. Germany (until the end of 2006), France, Sweden, Spain. National tax incentives have also played a major role in the USA, which have become the largest producer of fuel ethanol worldwide [Wiesenthal, 2007, 2009].

As the tax exemption must not exceed the level of the fuel tax, the instrument has proven most successful in countries with fossil fuel tax levels that compensate the additional production costs of biofuels compared to the fossil alternatives. This relation becomes very clear for Germany, where the introduction of a continuously rising ecotax on fossil fuels from 1999 onwards combined with a full tax exemption for biofuels eventually led to biodiesel pump prices falling below those of fossil diesel. As a result of a tax exemption of 47 ct/l for biodiesel in 2005, the highest level among EU Member States (Figure 4), biodiesel accounted for more than 6% of all diesel sold in Germany at that time (in energy terms).

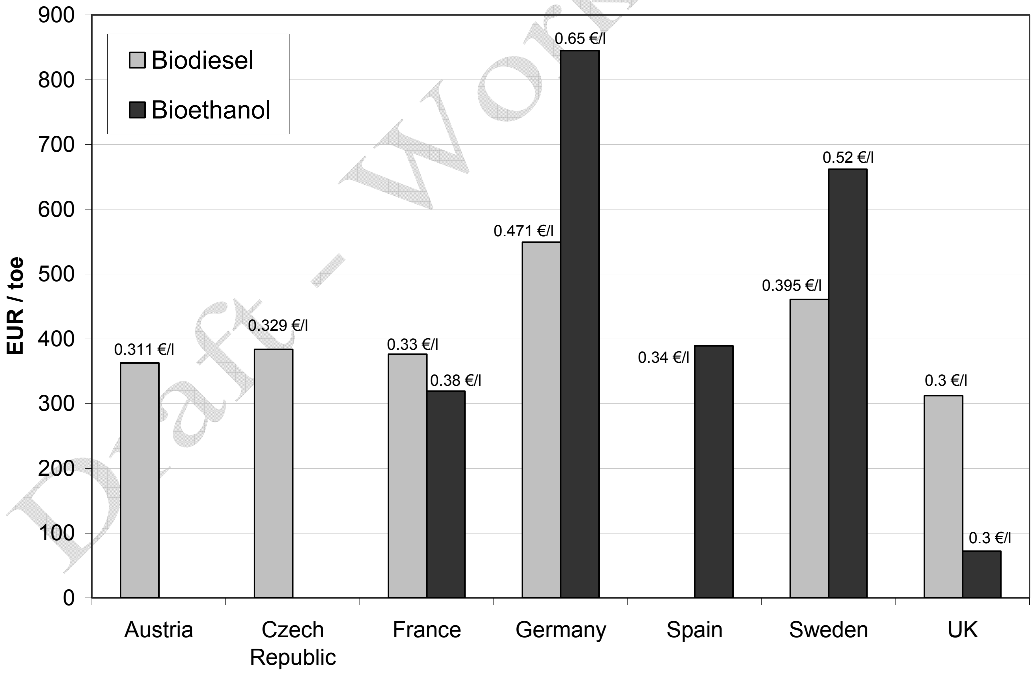

Figure 4: Level of tax reduction (in €/toe) in 2005 by Member State (the corresponding tax reduction level in volume term is also indicated for information)

Source: based on [Pelkmans, 2006]

Note: Energy contents used: Biodiesel: 33.1 MJ/l; Diesel: 35.9 MJ/l; Bioethanol: 19.6 MJ/l; Gasoline: 32.2 MJ/l

2.3.2. Feedstock Subsidy

Support to the cultivation of agricultural feedstock production in the EU is determined by the Common Agricultural Policy. Since 1992, bioenergy crops may be cultivated on set-aside areas that do not allow for the production of food crops up to a certain amount, agreed upon in the Blair House Agreement. The 2003 CAP reform also introduced a special aid for energy crops of 45 €/ha to support the cultivation of bioenergy feedstock [EU, 2003d].

Farmers have used the energy premium to a large extent. By 2006, the energy premium was applied for on almost one half of the land used for bioenergy production, another third was grown on set-aside land. Nevertheless, the extra revenues for the farmers remain limited: with an average yield of 3-4 tonnes of rapeseed per hectare, the premium would create extra revenue of 10-15 €/ton, on top of the market price of 200-250 €/ton. Moreover, the instrument is not suitable for reducing the overall production costs of biofuels: production costs are estimated to be reduced by only 0.03-0.04 €/litre for biodiesel and by 0.01-0.02 €/litre for bioethanol [Pelkmans, 2006].

In the medium term, this scheme can nevertheless become a suitable instrument for guiding the biofuel market to promote certain type of crops. Member States might, for example, create an incentive for dedicated energy crops that combine a high yield with limited environmental impacts. A first step in this direction was already made with the reform of the energy crop premium by including multiannual crops. Also the PREMIA biofuel scenarios indicate the potential of this policy in pushing advanced biofuels based on multiannual crops [Wiesenthal, 2007].

2.3.3. Capital subsidy

Capital investment support to biofuel production facilities is another supply side instrument. So far, however, it has only played a limited role in promoting biofuels. This is largely due to the fact that for conventional biofuel production facilities, the investment costs are rather small compared to the cost of feedstock. According to [JEC, 2006], they are in the range of 7% (biodiesel) to 30% (bioethanol).

This may change drastically with the advent of advanced 2nd generation biofuel technologies. Here, capital costs account for the large part (more than 60%) of total production costs. A capital investment subsidy is thus well suited to promote advanced biofuel technologies in their infant stage. The scenarios developed within the PREMIA project illustrate this effect: assuming a subsidy covering 50% of the capital costs of the production facilities on top of a biofuel obligation scheme, the share of lignocellulosic ethanol in total fuel demand might increase by a factor of ten [Wiesenthal, 2007]. On the other hand, however, such a complementary policies leads to additional costs that are borne by governments.

2.3.4. Obligations to fuel providers

The most direct way of increasing the share of biofuels is by establishing obligatory substitution levels for the transport fuel sold to consumers. The obligation falls onto the oil companies/ fuel distributors to sell a certain share or a fixed amount of biofuels, which may in return imply that this instrument is more difficult to implement. It is very reasonable to assume that the additional costs would eventually be passed on to the final transport users.

One of the major advantages of the obligation to fuel suppliers is the predictability of the market volumes that will be reached in a certain year. As the fuel supplier is obliged to fulfil the quota, this is the expected amount that will enter the market, unless an alternative mechanism seems more attractive. An obligation system thus sets a long-term, predictable framework to the biofuel producers, which consequently have a higher investment security, compared to the case of tax exemptions that can be revised every year, depending on the States' income needs. On the other hand, if the annual targets are set too low, the obligation may not exploit the full potential of biofuels.

In theory, the average direct cost for each litre of conventional fuel displaced would be similar to the one in the tax reduction case, the main difference being that the effects on the government budget would be almost neutral (apart from implementation and monitoring costs, and second-order effects to the economy). Costs would be carried by the oil industry and are likely to be passed on to the final transport users through higher fuel prices. This in return may reduce transport demand compared to a tax exemption scheme borne by the government, which is, however, rather supportive to the key drivers underlying biofuel support.

Despite the advantages for the public budget, an obligation system contains a number of potential drawbacks. One of the major risks is related to the incentive for fuel suppliers to opt for the lowest cost biofuels. While this ensures achieving a certain share of biofuels at low costs, it risks at having drawbacks on fulfilling the key objectives behind the biofuel support unless additional instruments are employed to steer the market. A likely effect is, for example, a higher share of imports, resulting in less support to domestic agriculture. Also low-blend fuels are likely to be favoured, and fewer incentives for innovation created.

This means that obligations may be an efficient instrument for increasing biofuel consumption, but are less appropriate for promoting a special type of biofuel. Other or complementary policies will prove more effective in pushing pure or high blends or certain technologies.

2.3.5. Double Counting

The policy instrument double counting refers to a quota which has the characteristics discussed in the section above. Additionally the rule applies that 2nd generation biofuels count double. The idea behind is to foster 2nd generation biofuels. By counting them double the market entry shall be earlier.

The reason to support 2nd generation biofuels is multifold. Firstly, their specific GHG emissions are lower than the GHG emissions of 1st generation of biofuels. Secondly, the interference with agricultural commodities is lower. Thus, a high share of 2nd generation biofuels might have a lower impact on food prices than the 1st generation of biofuels. Thirdly, 2nd generation biofuels are more capital intensive. Therefore, it seems more realistic that they can be produced on a competitive price compared to imported biofuels that in the case of 1st generation biofuels.

2.3.6. Policy summary

The main instruments to support biofuels are the tax reduction and the quota. With respect to the quota the idea of double counting second generation of biofuels came into the picture. In addition to the main instruments that primarily aim at creating a market demand – tax reduction and obligation – a variety of other, often complementary policies exist. These comprise supply side measures such as agricultural feedstock support or grants to production facilities as well as demand side measures such as the promotion of dedicated biofuel vehicles. While their impact on the promotion of biofuels has been rather limited in the past, they may become important additional instruments in the future as they allow the promotion of some specific biofuel production pathways. On the other hand, all complementary measure cause additional direct costs compared to a least-cost approach.

Scenario	Policy description
Reference	No biofuel support policies
Tax exemption	A tax reduction of 30%
Capital grant	A capital grant of 25%
Feedstock subsidy	A feedstock subsidy of 10%
Quota	A quota of 10% in 2020
Double Counting	A quota of 10% in 2020 and at the same time 2nd generation biofuels count double

Table 1: Overview on Policy Scenarios

3. SENSITIVITY ANALYSIS

3.1. Method

The deployment of biofuels in the transport market depends on a variety of factors, some of which are inherently uncertain such as the outlook on the oil and feedstock prices or trends in advanced biofuel conversion technologies. These uncertainties will need to be taken into account when conducting a model-based assessment of the effectiveness of future biofuel policies.

Every type of modeling is associated with uncertainties in its input parameters. Firstly, there is only limited knowledge of the assessor on structural model parameters (e.g. elasticity). In theory, this type of uncertainty could be reduced with the aid of further research. Secondly, some uncertainty occurs from the inherent randomness of exogenous variables (e.g. population growth).

In this paper a sensitivity analysis is applied that combines standard elements of a Monte Carlo approach with policy evaluation methods. This results in a sensitivity analysis containing six steps:

- Identify the input parameters with crucial impact on model output
- Assume (based on statistical evidence) their distribution ranges
- Run the deterministic model a high number of times with random sampling of the parameters (Monte Carlo Simulation)
- Obtain the expected distribution of the variable of interest (and the confidence range)
- Rank policy options by the expected opportunity loss
- Analysis systematical differences of input parameters for policy options with similar evaluation

Clearly, step one to four refers to the Monte Carlo approach, step five and six to policy evaluation methods. In detail the steps of the sensitivity analysis can be described as follows:

In a **first step**, we apply a straight-forward sensitivity analysis for each of the key parameters in order to determine the separate effect of every individual parameter on the model results. This step allows detecting the parameters with the largest impact on the model results; by restricting the following steps on these parameters, excessive research and computation efforts can be avoided. Each of the main parameters of the model is varied two hundred times in a random manner within a pre-defined uncertainty range of ±30% for all parameters. The parameters are ranked by their impact on the key model outputs, measured as the standard deviation of the resulting distribution (normalized to the mean value). On this basis, the most influential input parameters are selected.

In a **second step**, a literature review is undertaken with the aim of identifying uncertainty ranges, and ideally probability density functions, for the most influential parameters. Where there has been no indication of the shape of the probability density function, its shape and uncertainty range has been estimated on the information available.

The **third** and central **step** uses the Monte Carlo simulation method with 10000 iterations (chosen as a good compromise between an acceptable running time and a high number of trials) for assessing the combined effect of all uncertainties of the most influential parameters on the model outcomes. A Monte Carlo simulation is based on the repetition of many individual model runs with every single run using a randomly constructed set of input parameters following their probability distribution, and with all model outputs then being aggregated into a probability distribution of selected output variables {Hammersley and Handscomb, 1964]. Compared to a deterministic risk assessment based on distinct sensitivity runs (e.g. each parameter adopts three possible values), a Monte Carlo Simulation takes into account the probability distributions of each of the parameters and thus provides a smaller range of the outcomes than equally weighted sensitivity runs; furthermore, it automatizes the process of creating a high number of iterations.

Instead of a traditional Monte Carlo random sampling simulation, the 'Latin Hypercube Sampling' can be applied in order to improve the efficiency of the process and thus reduce the number of iterations that are required. While the Monte Carlo method selects input parameters completely randomly, the latin hypercube sampling first subdivides the uncertainty space defined by the combined uncertainty ranges of all parameters in strata of equal probability and then samples once from each stratum [McKay, 1979]. This means that the segment used for sampling the first random number is marked and therefore, the second random number will be drawn from another segment. As a consequence of this systematic sampling process, the probability distributions are being reproduced with a much lower number of iterations than with a Monte Carlo simulation, as illustrated e.g. by [McKay, 1979] and [Vose, 2000].

The Monte Carlo Simulation in this work is carried out with the built-in feature of VENSIM, the modeling platform on which the BioPOL model is being constructed.

The main objective of this risk assessment is to verify whether the model outputs allow to identify the preferable of several policy options in the presence of uncertainties. Hence, the Monte Carlo Simulation is applied for two distinct (simplified) policy cases. First results are the probability density functions of key output parameters of the two cases.

In order to avoid any combination of parameter values that are meaningless, correlations between parameters need to be identified and respected in the Monte Carlo simulation [Elston, 1992]. In the present application, such correlation is intended to avoid the construction of impossible cases of, for example, very high rapeseed prices and very low sunflower prices. The probability density functions of correlated variables are constructed based on a series of calculations based on Todd and Ng [Todd, 2001] and Burgman et al. [Burgman, 1993], and implemented through a combination of Excel-functions and random parameters generated within VENSIM. This process and the underlying equations are described further in Annex 1.

Given that these probability density functions may have an important overlap, a **fourth step** is applied in order to more clearly identify the policy case that bears the lowest risk of being the wrong decision. Here, the scenario results are compared among one another for every single set of randomly chosen input parameters. In order to make the difference between the alternatives clearer by eliminating the uncertainty that is common to both of them, it is necessary to compare the results of the two policy scenarios for the same randomly chosen input values. In the present work this is being realised by exogenously producing the 10000 sets of random variables and then feeding them back to VENSIM. Once done for all iterations, the comparison reveals the probability of policy scenario A in obtaining a higher value of a target variable than policy scenario B throughout all iterations without paying attention to the actual value achieved in the scenario.

The **fifth step** extends this approach by not only comparing which scenario ranks best, but also taking into consideration by how much it performs better, the expected opportunity losses of the best course of action can be calculated (see e.g. [Schlaifer, 1959], chapter 7 for an illustration). The expected opportunity loss of a scenario describes the difference between the expected benefits realised under that scenario and the expected benefits that would have been realised if the scenario had been the best course of action, i.e. the one with the lowest opportunity loss. As above, a precondition for this step is that alternatives are being compared for the same random input values. For every iteration the total benefits (here: the benefits of the avoided emissions of GHG minus their avoidance costs) are being calculated for the scenarios and then compared between them. Obviously, in each iteration the scenario that ranks best in terms of total benefits is associated with an opportunity loss of 0 as it already presents the best alternative to chose. If the policy-maker would, however, opt for an alternative option instead of using the best one, opportunity losses occur that equal the absolute value of the difference in benefits between the best option and the one that is selected. The opportunity costs for each scenario are then weighted by the probability of the iteration to take place (which would be 1/10000 runs in the present case). The resulting figure represents the expected opportunity loss that is associated with each of the policy scenarios; the ideal course of action is the one that minimizes the opportunity losses.

The expected opportunity loss associated with the best scenario is the 'inherent cost of uncertainty' as it represents the difference between choosing the best option with the available information and the best option with having perfect information (which would have an opportunity loss of 0 for all iterations, i.e. under all possible states of the world). It thus represents the maximum value that a decision maker would be willing to pay for perfect information. At the same time, if a decision maker chose an option other than the best one, the difference in the expected opportunity losses of that option and of the best option signifies the cost of irrationality [Schlaifer, 1959].

In the **sixth step** a further differentiation between the investigated policy scenarios is undertaken. It is only carried out for those policies where the economic assessment and the calculation of the opportunity losses come to similar results. In these cases it is analysed in which scenario conditions policy scenario A is better than policy scenario B. To this end the mean value of the inputs of the different scenarios are compared.

In the following the outcomes of the different steps of the Monte Carlo approach are described.

3.2. Ranking of parameters

In order to rank the input parameters by their impact on the model outcome, sensitivity iterations are performed separately for each individual input parameter (step 1 in section **Error! Reference source not found.**). Each of the parameters is varied with ±15% and ±30%. Then, the impact on the cumulative avoided CO2 emissions reductions is analysed. It is necessary to look at two time periods as some effects like learning of 2nd generation biofuels gain later of importance than e.g. improvements for the 1st generation biofuels. Thus, the cumulative avoided CO2 emissions are calculated for the time period from 2009 to 2020 and from 2009 to 2030.

Based on the above analysis, the most influencing parameters are derived (see Appendix Table 7). The oil price is by far the most important factor. Feedstock prices, emission factors, the CO_2 value have as well a high impact on the cumulative avoided CO2 emissions reductions. Learning rates of 2nd generation biofuels become important for the time after 2020.. Furthermore, the worldwide supply curve and the additional costs that occur at high blends of biofuels have to be considered. For those input parameters uncertainty ranges and probability distributions are applied in the next step.

3.3. Uncertainty ranges

3.3.1. Oil price outlook

Predictions for the oil prices (in real terms) that may prevail by 2030 comprise levels as low as 30US$/bbl (EIA-DoE, 2006). However, more recent scenarios such as the IEA's World Energy Outlook 2008 assume an average price of some 100 US$ per barrel until around 2015, followed by a linear rise to reach more than 120 US$ per barrel by 2030 (IEA, 2008c).

Given the broad span of prices, we assume an elevated uncertainty regarding the future trends in the oil price. It is assumed that with equal probability (i.e. uniform probability density function), the oil price (in real terms) could adopt values between 55 and 140 US$ per barrel by 2020 (equivalent to around 40-100 EUR/bbl), and remain constant thereafter until 2030.

3.3.2. *Biofuel production costs*

Table 2 summarises the production costs for the main biofuel pathways considered in the BioPOL model, collected from a variety of sources. The most comprehensive source of numerous biofuel production pathways and the related costs and GHG emissions in Europe is the study by JRC/EURCAR/CONCAWE on the Well-to-Wheel Analysis of future automotive fuels and powertrains in the European context. To the extent possible, it has thus been used as a reference in its version 2c from March 2007 [JEC, 2007]. Other information sources on biofuel production costs include OECD [OECD, 2008], DEFRA [DEPFRA, 2008], DFT [DFT, 2006], the Energy Charter Secreteriat [Energy Charter Secreteriat, 2007], as well as Hamelinck and Faaij [Hamelinck, 2006] and results from the research project TRIAS [Toro, 2006].

	Year: 2010		
	Central value used in BioPOL [EUR/toe]	Lower value found in literature [EUR/toe]	Upper value found in literature [EUR/toe]
Biodiesel from rapeseed	800	590	1480
Biodiesel from sunflower	750	720	950
BTL from wood waste	1000	900	1200
BTL from farmed wood	1150		
Ethanol from sugar beet	750	650	1200
Ethanol from wheat	800	520	1200
Ethanol from sugar cane	300	240	570
Cellulosic ethanol from straw	900	730	1150
Cellulosic ethanol from farmed wood	1110		

Table 2: Range of biofuel production costs

The wide range of estimations for biofuel production costs becomes obvious. To some extent, this is due to differences in the regional focus (affecting e.g. labour costs), the treatment of benefits obtained for by-products or (minor) differences in the pathways considered. More importantly, the production costs of first generation biofuels largely depend on feedstock prices. With feedstock prices having experienced a drastic surge in recent years followed by a decline afterwards, biofuel production costs vary significantly across years, as can be seen in **Error! Reference source not found.** (OECD, 2008a).

3.3.3. *Learning effects*

Learning plays an important role for the market introduction of advanced 2nd generation biofuels. These are expected to be technically available on commercial scale between 2010 and 2020, although their commercial viability will depend on how competitive their prices will be. Important cost reductions can be expected both in terms of the production process due to economies of scale and an increasing maturity of processes and components.

Additional cost reductions may also materialise for feedstock, as current crops are not yet optimised for their energy content; given that the feedstock costs of 2nd generation biofuels are below 30-40% of total production costs (compared to some 70-90% for first generation processes), it can nevertheless be assumed that the greatest cost reduction and leverage lies in the conversion process.

As data on 2nd generation biofuels are limited, learning effects can be quantified to a limited extent only. In most cases costs seem to be still relatively high in 2020, although there is a general agreement that, given sufficient investment and scale, 2nd generation technologies will start to become competitive around that time. Cost reductions will depend on a number of factors that – according to IEA (2008a) include the following:

- Continuous strong public and private support to R&D;

- Demonstration and pre-commercial testing;
- Development of measures of environmental performance;
- Better understanding of relevant biomass resources and geographical availability.

Hence, uncertainties remain elevated. The following uncertainty range of the cost reductions stemming from technological learning is identified and will form part of the Monte Carlo simulation:

- For BtL, production cost reductions are assumed to be around 35%-50% below 2010 values by 2030, the central value being a reduction of 40%. On an annualised basis, this is equivalent to a learning rate of 3.1% p.a. for capital cost.
- In the case of ligno-cellulosic ethanol, production costs are estimated to be 40 % below 2010 values by 2030 within the range of 35%-55%. On an annualised basis, this is equivalent to a learning rate of 3.8% p.a. for capital cost.

On this basis, we assume a uniform probability distribution of the learning factors in the interval span by the minimum and maximum values, as we have no information about which value is the most likely to occur.

3.3.4. Additional costs at higher blends

Bioethanol can be used in different ways to replace fossil based gasoline: as low blends (up to 10%) in the car fleet or high blends (85% and above) in dedicated flexi-fuel vehicles, or as ETBE to replace MTBE in the fuel production processes. ETBE is an additive to enhance the octane rating of petrol as a replacement of the fossil MTBE (replacing lead and benzene in unleaded petrol). It is produced by etherification of ethanol and isobutylene or natural gas. While the previous EU fuel quality directive (EU, 1998, 2003) limited the blending of ethanol to 5% in volume terms, a recent revision now allows for the use of blends up to 10% if acceptable vapour pressure limits are not exceeded and suppliers continue to ensure the availability of fuels with a maximum ethanol content of 5% until 2013 (EU, 2009b). In addition to the direct blending of ethanol into petrol, it can be used to produce ETBE (ethyl-tertiary-butyl-ether). Also for ETBE, the fuel quality directive sets a maximum limit for 15% in volume terms. As the ethanol content of ETBE is 47%, exhausting the maximum level implies that a bioethanol content of 4.7% on energy basis can be achieved in the fuel through ETBE. Resulting from this, the model assumes that additional costs occur at a bioethanol share of 11.5% in gasoline (i.e. the limit of ETBE plus E-10). Beyond this level, ethanol is typically be used in flexi fuel vehicles as a blend of 85% ethanol and 15% petrol (E-85). This causes additional cost that reflect the adaption of vehicles as well as the need for a dedicated infrastructure. Currently, the purchase prices of Flexi-Fuel-Vehicles (FFV) are some 300-1000 EUR above the prices of comparable gasoline cars. Assuming an average purchase price of 20000 EUR for a new vehicle, the additional costs are some 3%. Given that maintenance and fuel costs account for (at least) one third of total costs, we assume that the costs per kilometre increase by not more than 2% due to the adaptation of engines. The additional infrastructure costs are taken from JEC (2007) and lie in the order of around 2ct/km.

Biodiesel replaces fossil diesel and can be blended in different shares. Current legislation limits the maximum blend of biodiesel in fossil diesel to 5 % in volume terms, equalling 4.6% in energy, mainly because of concerns over the stability of biodiesel. Within the model it was assumed that a revision of the European Standard EN 590 which allows a maximum blending of 10% in terms of volume (9.2% in energy terms) for biodiesel will take place , as mandated by the European Commission (mandate M/394). For a deployment beyond such a level additional distribution and storage costs were assumed that are slightly below those of bioethanol due to the more limited adaptation needs of the engines.

We assume that the uncertainties related to the additional costs lead to a normal distribution of additional costs with a double standard deviation of 50% of the central values of 5 ct/l for bioethanol and 3.5ct/l for biodiesel.

3.3.5. *Well-to-wheel emissions of GHG*

Consistent with biofuel production costs, data on well-to-wheel emissions of greenhouse gases are taken from (JEC, 2007) to the extent possible, complemented with information from other sources. A broad range of WTW emission is span by different production pathways, strongly influenced by the use of by-products and the source of the energy needed for the conversion process originating e.g. from lignite-based or biomass-based electricity.

Figure 5 provides an overview of the reduction of various types of biofuels when substituting fossil fuels. It also shows the related uncertainty ranges. The values shown lie well within the range determined by an analysis of 60 studies (OECD, 2008a), even if the latter study comes up with much broader ranges.

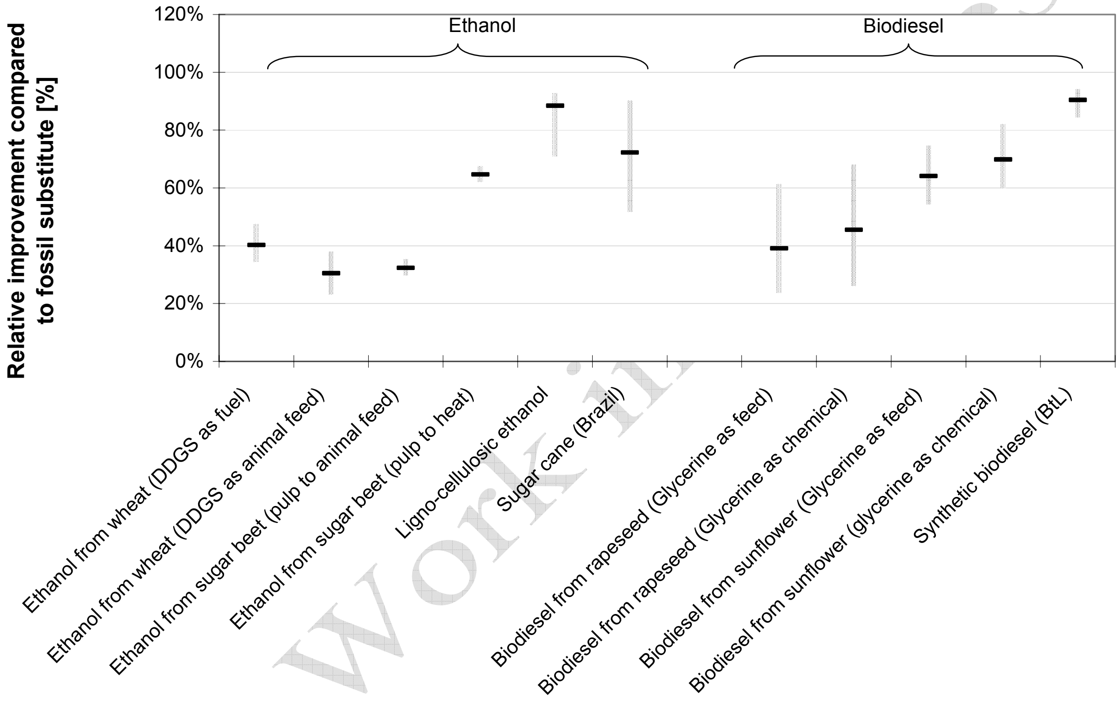

Figure 5: Relative improvement in well-to-wheel emissions of GHG for different biofuel production pathways compared to fossil diesel and gasoline

Source: JEC, 2007; JEC, 2008

Note: For the min and max ranges the uncertainties provided in JEC (2007) are used. Some values have been updated with figures provided in JEC (2008).

3.3.6. *Import supply curves*

Sugar-cane based bioethanol can be produced at significantly lower costs than the domestically produced equivalent (see Table 2). Given that biofuels are an easily tradable commodity, imports can be assumed to play a significant role in the European biofuel consumption.

The underlying cost-supply curves are taken from work undertaken under a contract for the JRC-IPTS [Resch, 2009]. They are based on a combination of supply cost curves for diverse feedstock proposed by Kline [Kline, 2008] and the US Departement of Energy [DoE, 2008]. According to this estimation, approximately 11 Mtoe bioethanol could become available on the international market at a price of less than 800 €/toe by 2020, while 13 Mtoe would be available at a price below 1150 €/toe. Additionally 30 Mtoe are available below 1500 €/toe. By 2030, 15 Mtoe bioethanol are available for under 800 €/toe while 17 Mtoe are below 1150 €/toe. With regard to biodiesel, the international market quantities are lower. Approximately 1 Mtoe of biodiesel may be available for under 800 €/toe at the global market, expanding to roughly 7 Mtoe with higher prices up to 1200 €/toe. For 2030, 2 Mtoe are available for under 800 €/toe while approximately 11 Mtoe are available for under 1200 €/toe. The assumptions biofuel import prices are, however, associated with elevated uncertainties as they depend on a variety of factors both on the supply side (such as the development of feedstock costs, yields, conversion efficiencies) but also on the demand side (such as the biofuel targets set by individual regions).

3.4. Definition of probability density functions

The sensitivity analysis described in chapter 3.1 demonstrates that the key input parameters determining biofuel deployment and costs are the oil price; the costs of feedstock; the emission factors; the CO_2 value; the worldwide supply curve; the learning rate of 2nd generation biofuels; and, to a much lesser extent, the additional costs of high biofuel blends. In the following step, the model outputs are thus assessed on the basis of the combined uncertainties of these parameters. In addition, an uncertainty in the specific emission factors of the various biofuel production processes is included. Even though this parameter does not influence the central model outcome, it is crucial when determining one of the politically most relevant output variables of the model: the amount of greenhouse gas emissions that can be avoided when substituting fossil fuels with biofuels. The uncertainty ranges and probability distributions of the key parameters have been identified in chapter 3.3 and are summarised in Table 3.

Parameter	Mode (if applicable)	Min-Max range or standard deviation	Probability distribution function	Correlation with other parameters
Oil price	80 EUR/bbl	40 -120 (10-200 with lower probability)	Uniform/step	to feedstock prices
Feedstock price rapeseed	279 EUR/t	200 - 550	Skewed normal	See Appendix Table 8
Feedstock price wheat	140 EUR/t	90 - 250	Skewed normal	
Feedstock price straw	4.06 EUR/m3	3.29 – 5.19	Skewed normal	
Feedstock price wood waste	296 EUR/t	267 - 356	Skewed normal	
Feedstock price energy crops L-C ethanol	643 EUR/t	521 - 823	Skewed normal	
Feedstock price energy crops BtL	457 EUR/t	400 - 600	Skewed normal	
BtL: Production cost reduction due to learning 2010-2030	40%	35%-50%	Skewed normal	less relevant
LC-ethanol: production cost reduction 2010-2030	40%	35%-55%	Skewed normal	less relevant
Additional costs for high blends	5 ct/l	2.5-7.5	Normal	less relevant
World wide supply curve	e.g. 11 Mtoe at 800EUR/toe in 2020	5.5 – 16.5 (50% - 150%)	Normal	
Emission Factor Biodiesel (by-product animal use)	2.06 t CO_2/toe	1.30-2.67	triangular	
Emission Factor Bioethanol (by-product animal use)	2.53 t CO_2/toe	2.24-2.82	triangular	
Emission Factor Biodiesel (by-product energy use)	1.83 t CO_2/toe	1.06-2.55	triangular	
Emission Factor Bioethanol (by-product energy use)	2.00 t CO_2/toe	1.75-2.24	triangular	
Emission Factor BtL	0.35 t CO_2/toe	0.24-0.57	triangular	
Emission Factor LC-ethanol	0.42 t CO_2/toe	0.29-1.07	triangular	
Emission Factor Imports	1.01 t CO_2/toe	0.38-1.80	triangular	
CO_2 value	60 EUR/t CO2	20 – 100	uniform	

Table 3: Uncertainty and shape of the probability density distribution of key parameters [Schade, 2010]

Note: feedstock prices are given per ton of already processed feedstock, e.g. feedstock price of waste wood delivered to processing plant would cost around 60 EUR/t. Prices are provided in constant Euro$_{2005}$

3.5. Correlations

In order to eliminate meaningless combinations of input parameters, correlations between them had to be identified and then implemented. This is most relevant for the specific emission factors that stem from differences in the uses of by-products (e.g. the emission factor for biodiesel with by-product use as energy and of animal feed is set to 0.5), and for feedstock prices (see Appendix Table 8). The correlation across the uncertainties for agricultural commodities that are being used as feedstock are estimated on the basis of historic time series of prices taken from IMF, IPTS and complemented by expert guesses for those commodities for which no time series could be obtained.

3.6. Convergence criteria

The assessment has not been performed on a pre-defined number of Monte Carlo iterations. Instead, an assessment of the number of iterations that is needed for achieving stable outcomes has been performed. The Monte Carlo simulation has been tested with 10000 iterations. For each iteration the net present value of the net benefits was calculated. To determine when convergence is reached the following convergence criteria was applied for 2020 and 2030.

$$\frac{\left| NPV\left(net\ benefit_{N+1,t}\right) - NPV\left(net\ benefit_{N,t}\right)\right|}{NPV\left(net\ benefit_{N,t}\right)} < 0.1\%$$

In 2030 the iterations reached convergence after 7261 in the 'No Biofuel Support' policy case and 8769 in the 'Capital Grant of 25%' policy case (Figure 6). The other policy cases reach convergence not later than after 8769 iterations. In 2020 convergence was reached in both policy cases at 3447. Thus, 9000 iterations have been chosen as 'default' in the present assessment.

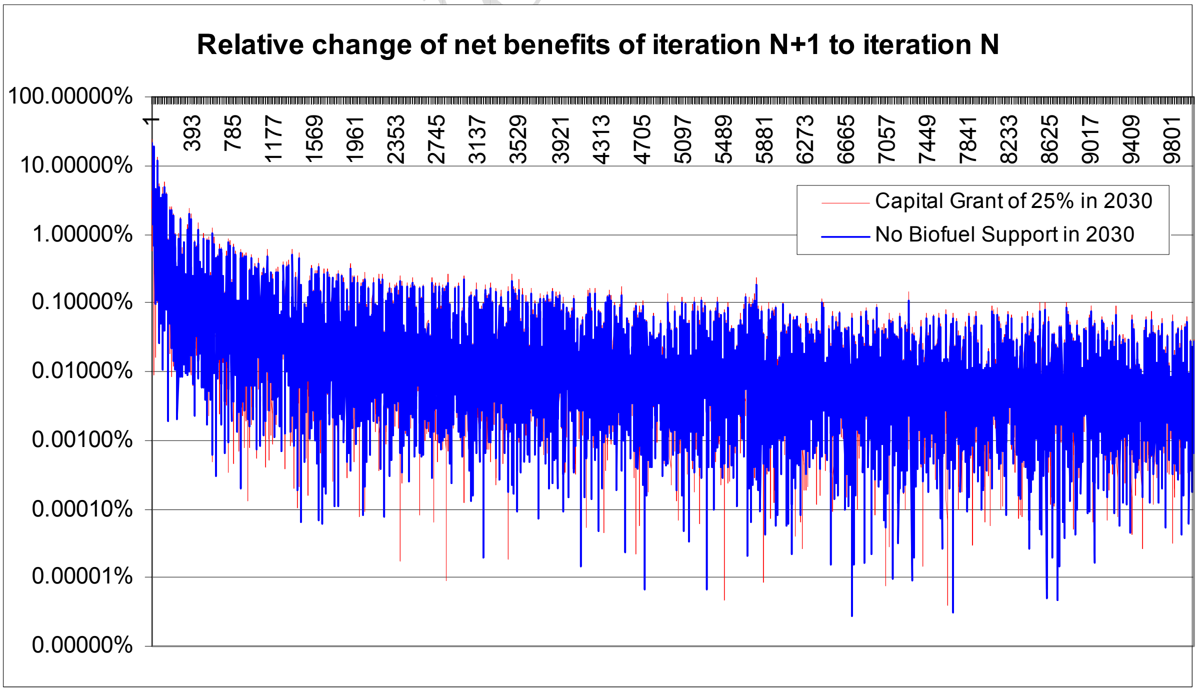

Figure 6: Change of NPV of net benefits within 10000 iterations

4. RESULTS

At the current stage not all policy instruments could be assessed completely. The analysis focus on the policy cases 'Tax Exemption by 30%', 'Capital Grant by 25%' and 'Feedstock Subsidy of 10%'. The analysis presents only preliminary results. The following chapters refer to the steps four, five and six of the sensitivity analysis.

4.1. Probability density functions of key output parameters

Figure 7 presents a histogram of net present value of the net benefit for the different policy cases. The net benefit is the key output parameter. The net benefit is determined as the avoided GHG emissions multiplied with the CO_2 value minus the additional cost due to the biofuel production.

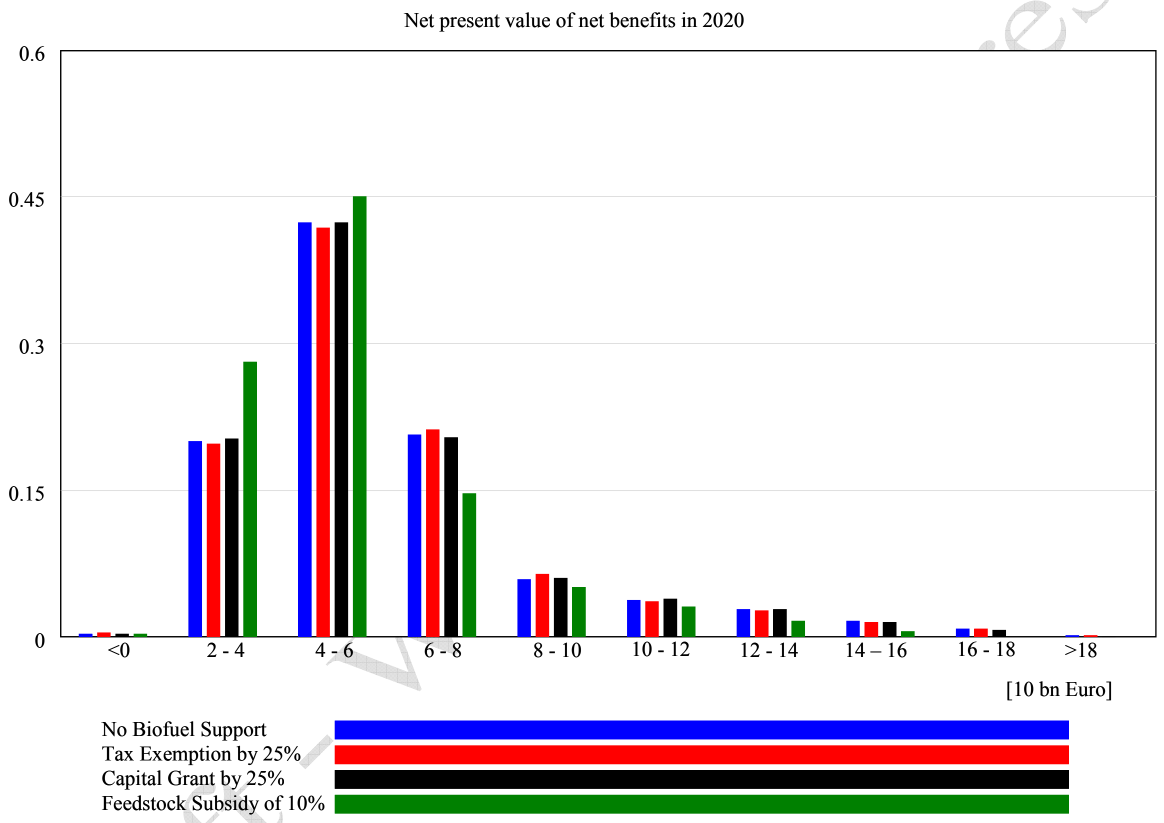

Figure 7: Histogram of the net benefits of different policy cases in 2020

Figure 7 shows that all four policy cases have a net benefit between 40 and 60 bn Euros with a probability of more than 40%. The policy case feedstock subsidy has a higher probability to be in the range of 20 to 60 bn Euros that the other three scenarios. However, the results are very close so that a clear distinction which policy case is the best is not possible

4.2. Risk assessment and opportunity losses

As the probability distribution of output variables does not immediately reveal a ranking of policy options, the options are assessed further with regard to their opportunity losses.

The **opportunity loss** of not taken the best scenario is calculated in a follow-up step. In the present work, this process is exemplified at the most aggregated output variable, the net benefits of avoided cumulative GHG emissions. Again, the outcome serves mainly as an illustration of the approach.

For every single iteration, the benefits – i.e. the price per tonne of GHG emission avoided minus the avoidance costs – are identified (see Table 4). From this, the opportunity losses are derived by simply subtracting the best possible outcome from the benefits of both scenarios. By definition, this sets the opportunity losses of the best performing scenario to 0 in each iteration, while the opportunity losses for the worse scenario are the (absolute of the) the difference in benefits. For each iteration, the expected opportunity losses are calculated by weighting the opportunity loss with the probability of the iteration. The sum over all iterations then provides the expected opportunity loss of every scenario (Table 5).

Note, however, that the higher opportunity losses of scenario B do not imply an overall negative outcome of this policy. On the contrary, both scenarios show a high net benefit for reducing GHG emissions (Table 4) under the assumptions made, but the 'No Biofuel Support' scenario performs (a bit) better than a 'Capital Grant by 25%' scenario.

Iteration no.	No Biofuel Support Bn EUR	Capital Grant by 25% Bn EUR
1	46.4	46.2
2	38.5	37.9
3	28.6	28.3
…	…	…
8	23.2	23.2
9	75.7	76.0
10	41.3	40.8
…	…	…
9000	126.8	122.3
average	**50.9**	**50.3**

Table 4: GHG net benefit in 2020 for a 'No Biofuel Support' and a 'Capital Grant by 25%' for iterations with randomly selected input parameters

Iteration no.	No Biofuel Support Mio EUR	Capital Grant by 25% Mio EUR	Probability of the iteration
1	0	165	1/9000
2	0	575	1/9000
3	0	364	1/9000
…			1/9000
8	0	86	1/9000
9	283	0	1/9000
10	0	471	1/9000
…			1/9000
9000	0	4549	1/9000
sum over opportunity losses weighted by probability	**5**	**506**	

Table 5: Opportunity losses in 2020 for a 'No Biofuel Support' and a 'Capital Grant by 25%' scenario for iterations with randomly selected input parameters

The expected opportunity losses related to the optimal course of action (here: the 'No Biofuel Support' scenario) are 5 million Euros in 2020. These costs can be called the cost of uncertainty. The costs of irrationality are the expected opportunity loss of the wrong course of action (here: the 'Capital Grant by 25%' scenario) minus the opportunity less of the best scenario. These amount to almost 506 million Euros.

The comparison of the different policy cases with the 'No Biofuel Support' policy case in 2020 and in 2030 leads to Table 6. In 2030 the dominance of 'No Biofuel Support' policy case is clear. The other policy cases correspond all with very high expected opportunity losses.

Expected opportunity loss	2020	2030
No Biofuel Support	5	0
Capital Grant 25%	506	21,317
Expected opportunity loss	2020	2030
No Biofuel Support	390	0
Tax Exemption 30%	465	16,616
Expected opportunity loss	2020	2030
No Biofuel Support	2	4
Feedstock Subsidy 10%	8,998	54,246

Table 6: Expected opportunity losses of different policy cases compared to 'No Biofuel Support'

In 2020 only 'Tax Exemption by 30%' has comparable expected opportunity loss compared to the 'No Biofuel Support'. In 49.9% of all iterations the 'Tax Exemption by 30%' has a higher net benefit that the 'No Biofuel Support'. Table 6 shows us that the 'No Biofuel Support' is the best policy case among those selected. However, a detailed analysis of the degree of tax exemption, capital grant and feedstock subsidy is necessary to finally evaluate the policy cases.

4.3. Relevant input parameter for the assessment of the policies

In the last step of the analysis we investigate why in some iterations the 'Tax Exemption by 30%' is better that the 'No Biofuel Support' and why in others not. To this end the average of the input parameters are compared.

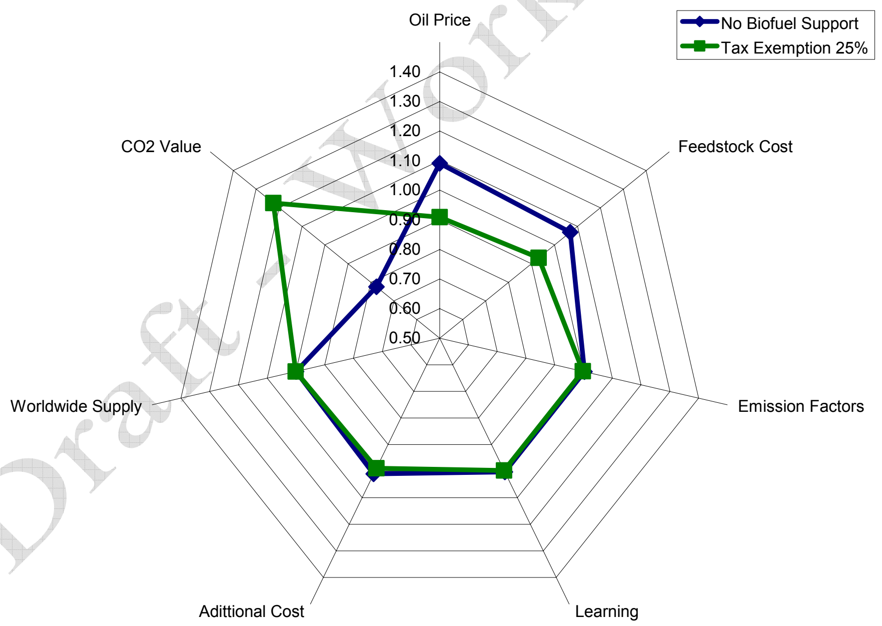

Figure 8: Comparison of the mean values of the different policy cases with the mean value of all iterations

In the first step the mean value of the input parameter (e.g. oil price) of those iterations where the 'No Biofuel Support' has the lower expected opportunity loss is calculated. In the second step the mean value of the same input parameter (e.g. oil price) of all iterations is determined. In the last step both mean values are divided. The blue line indicates the mean value of those iterations where the 'No

Biofuel Support' has the lower expected opportunity loss divided by the mean value of all iterations. The green line indicates the mean value of those iterations where the 'Tax Exemption by 30%' has the lower expected opportunity loss divided by the mean value of all iterations.

For the input parameters worldwide supply, additional cost, learning of 2nd generation biofuels and emission factors the mean values are 1. This means that those input parameters don't influence the ranking between the policy cases.

Figure 8 shows that those iterations where 'Tax Exemption by 30%' is the better policy case correspond with a higher mean value of CO_2 values. The results seem plausible as we derive higher avoided GHG emissions in the 'Tax Exemption by 30%'. A higher CO_2 values leads to an increase of the benefits of avoided GHG emissions. Together high CO_2 values improve the benefits of avoided GHG emissions more for the 'Tax Exemption by 30%' than for the 'No Biofuel Support' policy case.

High feedstock prices lead to the opposite result. Higher feedstock prices lead to higher additional cost through the biofuel production. Furtehrmore, the amount of biofuel production is higher in the 'Tax Exemption by 30%' than in the 'No Biofuel Support'. This means that higher feedstock costs generate higher additional cost and, therefore, lower net benefit for the 'Tax Exemption by 30%'.

High oil prices lead to better results of the 'No Biofuel Support' policy case. As one can see from the model description (chapter 2) oil prices have a high impact on the biofuel market. On one hand, high oil prices lead to an increase of fossil fuel prices. This leads to lower additional cost per unit of biofuel compared to fossil fuel. On the other hand, high oil prices affect the feedstock prices in the same direction. As feedstock prices rise they reduce the additional cost per unit of biofuel compared to fossil fuel. Both effects seem to outweigh somehow. In addition, higher oil prices bring more biofuels into the market. This means that in iterations with high oil prices the biofuel share is already high. In those cases the 'Tax Exemption by 30%' brings additional quantities of biofuels into market which is due to the high amount of biofuels costly. In total, the economic evaluation worsens for the 'Tax Exemption by 30%' with high oil prices.

5. CONCLUSIONS

Modelling the deployment of biofuels can contribute to identifying efficient policy options for achieving the European biofuel objectives. At the same time, however, the market uptake of biofuels depends on a large variety of factors, some of which are inherently uncertain and/or vary over time and/or space, such as the development of the oil or feedstock prices. Furthermore, not all parameters within a simulation model can be defined to a satisfactory degree. It is thus of vital interest to assess whether the prevalence of uncertainties impedes the evaluation of distinct policy options, or whether a model-based assessment can nevertheless provide results at a sufficiently high level of certitude.

A systematic risk assessment has been carried out for the biofuel simulation model BioPOL. In the first step, a sensitivity analysis demonstrated that key parameters influencing the take-up of whatever type of biofuels are the oil price, which largely determines the price of the fossil fuel they substitute, and the feedstock prices, which dominate the biofuel production costs. Outlooks for both of these parameters are highly uncertain due to diverse factors influencing their respective price developments, including resource constraints but also speculation. At the same time the uncertainty analysis reveals that many of the model-inherent parameters play a minor role, thus endorsing the model calibration.

As a consequence of the wide probability density functions of key input parameters the combined Monte Carlo simulation generated a wide-spread range of possible results of decisive model output parameters, such as the production volumes or unit production costs. On this basis, no clear evaluation of the set of (theoretical) policy options assessed here could be undertaken.

A clear distinction of the impact of distinct policies on central model output variables is, however, possible. Building up on the Monte Carlo Simulation and comparing for every single run the model results of the two scenarios with identical sets of random parameters allows identifying the probability of one scenario achieving a higher value than the other option under all possible states of the world. Going one step further and assigning the opportunity losses to every pair of iterations, the risks associated with best performing scenario and the losses for taken the wrong course of action can be evaluated.

This clearly allows a ranking of the chosen policy options, indicating that a 'No Biofuel Support' scenario is preferable to the other policy cases. Note, however, that scenarios 'No Biofuel Support' and 'Tax Exemption by 30%' are relatively close in absolute terms and would both achieve considerable benefits through the reduction of GHG under the assumptions made.

The last step of the sensitivity analysis takes a closer look at the input parameters. Comparing the mean value of those iterations where 'Tax Exemption by 30%' is the better option which those iterations where 'No Biofuel Support' is the better option gives us a hint on the most relevant input parameters for the economic assessment. The CO_2 value, the high oil and the feedstock prices turn out to be most relevant for the economic assessment of the 'Tax Exemption by 30%' policy case.

The paper exemplifies that a risk assessment of distinct policy options is possible even under conditions of high uncertainty in input parameters. It requires a systematic analysis of the expected opportunity losses of the options instead of few randomly selected sensitivity runs. In further steps, the above approach could be applied to more realistic policy scenarios varying also the degree of policy options. Then, a clear distinction of a set of policy options could be carried out.

REFERENCES

Boerrigter, H. (2006): Economy of Biomass-to-liquid plants. An engineering assessment. ECN

Burgman, M.A., Ferson, S., Akcakaya, H.R. (1993): Risk Assessment in Conservation Biology. Chapman and Hall, London.

Casamassima, G., Martino, A., Schade B. (2007): High Oil Prices: a comparison of the main national and international studies. Deliverable 1 of HOP! (Macro-economic impact of high oil price in Europe). Funded by European Commission 6th RTD Programme. Milan, Italy.

De Santi, G. (Ed), Edwards, R., Szekeres, S., Neuwahl, F., Mahieu, V. (2007): Biofuels in the European Context: Facts and Uncertainties. JRC Report 44464.

DEFRA (UK Department for Environment, Food and Rural Affairs) (2008): Estimating the Cost-effectiveness of Biofuels. DEFRA Economics Group, April 2008

DFT (UK Department for Transport) (2006): International resource costs of biodiesel and bioethanol.

DG TREN (2009): EU energy and transport in figures.

Di Lucia, L., Nilsson. L.J. (2007): Transport biofuels in the European Union: The state of play. Transport Policy, Volume 14, Issue 6, 533-543.

DoE (US Department of Energy) (2008): World Biofuels Production Potential. Understanding the Challenges to Meeting the U.S. Renewable Fuel Standard. Office of Policy Analysis. Office of Policy and International Affairs. Washington, DC

EIA-DOE (2006): International Energy Outlook 2006

Elston, D.A. (1992): Sensitivity analysis in the presence of correlated parameter estimates. Ecol. Modell. 64, 11–22.

Energy Charter Secretariat (2007): Driving without petroleum? A Comparative Guide to Biofuels, Gas-to-Liquids and Coal-to-Liquids as Fuels for Transportation.

EU (1998): Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Directive 93/12/EEC (amended with 2003/17/EC).

EU (2003a): Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.

EU (2003b): Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels.

EU (2003c): Directive 2003/93/EC of the European Parliament and of the Council of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity.

EU (2003d): COUNCIL REGULATION No 1782/2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers and amending Regulations (EEC) No 2019/93, (EC) No 1452/2001, (EC) No 1453/2001, (EC) No 1454/2001, (EC) 1868/94, (EC) No 1251/1999, (EC) No 1254/1999, (EC) No 1673/2000, (EEC) No 2358/71 and (EC) No 2529/2001.

EU (2009a): Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/ECber States' Reports in the frame of Directive 2003/30/EC, 2004, 2005 and 2006 reports.

EU (2009b): Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EE

EurObserv'ER (2008): Biofuels Barometer June 2008.

EurObserv'ER (2009): Etat des énergies renouvelables en Europe. Edition 2008.

Hamelinck CN, Faaij APC. (2006): Outlook for advanced biofuels. Energy Policy 34(17): 3268-83.

Hammersley, J.M., Handscomb, D.C. (1964): Monte Carlo Methods. Methuen, London.

Hattis, D., Burmaster, D.E. (1994): Assessment of variability and uncertainty distributions for practical risk analyses. Risk Analysis Vol. 14, 713–730.

IEA (2008a): Energy Technology Perspectives 2008. IEA/OECD, Paris.

IEA (2008b): From 1st to 2nd generation biofuel technologies. An Overview of current industry and RD&D activities. IEA and IEA Bioenergy. IEA/OECD, Paris.

IEA (2008c): World Energy Outlook 2008. IEA/OECD, Paris.

JEC (JRC, EUCAR, CONCAWE) (2006): Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, WELL-to-WHEELS report, Version 2b, May 2006.

JEC (2007): Well-to-Wheels analysis of future automotive fuels and powertrains in the European context WELL-TO-WHEELS Report Version 2c.

JEC (2008): Well-to-Wheels analysis of future automotive fuels and powertrains in the European context. WELL-TO-TANK Report Version 3.0 November 2009. WTT App.2 - Description and detailed energy and GHG balance of individual pathways

Kahouli-Brahmi, S. (2008): Technological learning in energy – environment – economy modeling: A survey. Energy Policy 36 (2008) 138-162.

Kline, K.L., Wolfe, A.K., Perlack, R.D., Dale, V.H., McMahon, M. (2008): Biofuel Feedstock Assessment, ORNL.

Kutas, G., Lindberg, K., Steenblik, R. (2007): Biofuels – at what cost? Government support for ethanol and biodiesel in the European Union. Prepared for the Global Subsidies Initiative.

McKay, M.D., Beckman, R.J., Conover, W.J. (1979). A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code. Technometrics 21 (2): 239–245.

McLaughlin, M.P. (1999): Regress+, Appendix A: A Compendium of Common Probability Distributions. Version 2.3

OECD (2008a): Biofuel support policies: An economic assessment. OECD, Paris

OECD (2008b): Economic assessment of biofuel support policies. Summary of OECD report. OECD Directorate for Trade and Agriculture. Press Conference, Paris, 16 July, 2008.

Pelkmans, L., Portouli, E., Papageorgiou, A., Georgopoulos, P. (2006): Impact Assessment of measures towards the introduction of biofuels in the European Union. Report of Work Package 4 of the PREMIA project.

Pouliquen, L.Y (1970): Risk Analysis in Project Appraisal. World Bank Staff Occasional Papers No. 11, The Johns Hopkins Press, 1970.

Resch, G., Ragwitz, M., Panzer, C., Faber, T., Toro, F., Held, A., Hass, R. (2009): Beyond 2020 - Characterization of Alternative Renewable Energy Scenarios for the EU. Final report of a project contracted by JRC IPTS. Unpublished.

Russ, P., Wiesenthal, T., van Regemorter, D., Ciscar, J.C. (2007): Global Climate Policy Scenarios for 2030 and beyond – Analysis of Greenhouse Gas Emission Reduction Pathway Scenarios with the POLES and GEM-E3 models. JRC Reference Report, EUR 23032 EN.

Schade, B., Casamassima, G., Fiorello, D., Martino, A., Schade W., Walz, R. (2007): High Oil Prices: Scenarios assumptions and model interfaces. Deliverable 2 of HOP! (Macro-economic impact of high oil price in Europe). Funded by European Commission 6th RTD Programme. Seville, Spain.

Schade, B., Wiesenthal, T. (2010): Biofuels: A model based assessment under uncertainty applying the Monte Carlo method. Forthcoming.

Schlaifer, R. (1959): Probability and Statistics for Business Decisions, An Introduction to Managerial Economics under Uncertainty. McGraw-Hill

Staehr, K. (2006): Risk and Uncertainty Analysis in Cost Benefit Analysis. Institut for Miljøvurdering (Danish Environmental Assessment Institute).

Thrän, D., Weber, M., Scheuermann, A., Froehlich, N., Thoroe, C., Schweinle, J., Zeddies, J., Henze, A., Fritsche, U.R., Jenseit, W., Rausch, w., Schmidt, K. (2006): Sustainable Strategies for Biomass Use in the European Context – Analysis in the charged debate on national guidelines and the competition between solid, liquid and gaseous biofuels, IE-Report.

Todd, C.R., Ng, M.P. (2001): Generating unbiased correlated random survival rates for stochastic population models. Ecol. Model. 144, 1–11.

Toro, F.A., Hasenauer, U., Schade, W., Wietsche, M. (2006): Biofuels Technology Database. Deliverable of the TRIAS project: Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios.

van Thuijl, E., Deurwaarder, E.P. (2006): European biofuel policies in retrospect. ECN http://www.ecn.nl/docs/library/report/2006/c06016.pdf

Vose, D. (2000): Risk Analysis – a quantitative guide. 2nd edition. John Wiley & Sons.

Wiesenthal T, Schade B, Christidis, P, Leduc G, Pelkmans L, Govaerts L. (2007): Analysis of biofuel support policies. Proceedings of the 15th European Biomass Conference, Berlin, Germany, 7-11 May 2007

Wiesenthal, T., Leduc, G., Christidis, P., Schade, B., Pelkmans, L., Govaerts, L., Georgopoulos, P. (2009): Biofuel Support Policies in Europe: Lessons Learnt for the Long Way Ahead. Renewable and Sustainable Energy Reviews 13 (4); 2009, 789-800.

ANNEX – ADDITIONAL RESULTS OF THE MONTE CARLO SIMULATION

Change of cumulative avoided CO2 emission between 2009 - 2020 as percentage	**Change of output (relative to central value)**			
Parameter	**-30%**	**-15%**	**+15%**	**+30%**
Oil price	-18.3	-9.8	11.4	24.4
Oil price elasticity of biofuel production costs per type of biofuel	0.0	0.0	0.2	0.4
Reduction of production cost of ligno-cellulosic ethanol due to learning	-2.4	-1.2	1.3	2.5
Reduction of production cost of BtL due to learning	0.0	0.0	0.0	0.0
Feedstock prices for ligno-cellulosic ethanol by straw	2.2	1.2	-1.1	-2.0
Feedstock prices for BtL by waste wood	0.0	0.0	0.0	0.0
Feedstock prices for 2nd generation farmed wood	0.1	0.0	0.0	0.0
Feedstock price for 1st generation ethanol	-6.2	-4.5	5.8	8.9
Feedstock price for 1st generation biodiesel	15.1	6.8	-2.8	-4.5
Elasticity of feedstock costs for 2nd generation biofuel types	0.5	0.3	-0.2	-0.4
Elasticity of feedstock cost for each type of first generation biofuels	0.0	0.0	0.0	0.0
Additional costs that occur for high blends and represent the necessary adaptation of engines and infrastructure investments for both biodiesel (except BtL) and ethanol	0.6	0.4	-0.3	-0.5
Cost-supply curve of imports	-5.3	-2.7	2.8	5.6
Maximum depreciation determining the dismantling of existing capacity	0.0	0.0	0.0	0.0
Maximum capacity that can be added p.a.	-1.0	-0.5	0.6	1.2
CO_2 Price	-0.5	-0.2	0.3	0.6
Emission Factors	10.3	5.2	-5.2	-10.3

Change of cumulative avoided CO2 emission between 2009 - 2030 as percentage	**Change of output (relative to central value)**			
Parameter	**-30%**	**-15%**	**+15%**	**+30%**
Oil price	-51.4	-28.7	30.2	60.8
Oil price elasticity of biofuel production costs per type of biofuel	3.0	1.6	-2.0	-3.6
Reduction of production cost of ligno-cellulosic ethanol due to learning	-4.1	-2.2	2.7	5.3
Reduction of production cost of BtL due to learning	-5.4	-3.8	4.7	9.8
Feedstock prices for ligno-cellulosic ethanol by straw	3.6	1.8	-1.2	-2.1
Feedstock prices for BtL by waste wood	5.8	2.4	-2.5	-4.3
Feedstock prices for 2nd generation farmed wood	12.3	4.1	-2.3	-3.0
Feedstock price for 1st generation ethanol	15.8	6.2	-4.3	-5.6
Feedstock price for 1st generation biodiesel	13.4	6.6	-10.0	-13.1
Elasticity of feedstock costs for 2nd generation biofuel types	2.5	0.8	-0.8	-1.4
Elasticity of feedstock cost for each type of first generation biofuels	2.4	1.0	-0.7	-1.3
Additional costs that occur for high blends and represent the necessary adaptation of engines and infrastructure investments for both biodiesel (except BtL) and ethanol	3.2	1.7	-1.5	-3.0
Cost-supply curve of imports	-9.2	-4.5	4.7	9.3
Maximum depreciation determining the dismantling of existing capacity	0.0	0.0	0.0	0.0
Maximum capacity that can be added p.a.	-8.3	-3.7	3.2	5.6
CO_2 Price	-10.6	-5.2	5.3	10.6
Emission Factors	17.3	8.7	-8.7	-17.3

Table 7: Influence of changes in parameters on the model output 'cumulative avoided CO2 emissions' [Schade, 2010]

Prices of:	Wheat	Sugar-beet	Rape-seed	Sun-flower	Straw	Wood waste	Energy crops LC E	Energy crops BtL
Wheat	1	0.3	0.6	0.6	0.2			
Sugar beet		1	0.2	0.2				
Rapeseed			1	0.8				
Sunflower				1				
Straw					1			
Woodwaste						1		
Energy crops ligno-cellulosic							1	0.7
Energy crops BtL								1

Table 8: Correlations assumed between selected agricultural commodities [Schade, 2010]