Annex A.

Specification of Biofuel Markets in the Aglink Model

General description of the Aglink Biofuel Modules

Explicit biofuel modules have been developed for four Aglink regions which currently represent some 94% of global fuel ethanol production and 81% of world biodiesel production. These regions include the USA, Canada, the European Union and Brazil. The general module represents the production of biofuels, the production and use of by-products, and the biofuel use for transport. Furthermore, it considers foreign net trade which is balanced by world equilibrium prices on the global level. Separate markets are represented for the two major types of biofuels: ethanol, and biodiesel.

Within both types, the supply side of the model structure distinguishes between first-generation biofuels from agricultural commodities (cereals and sugar crops in the case of ethanol, vegetable oils in the case of biodiesel), second-generation biofuels from dedicated biomass production (*i.e.* cellulose based ethanol from crops such as fast-growing wood or grasses, and synthetic biodiesel from biomass crops), second-generation biofuels from crop residues (in particular from straw), and other biofuels (including fuels derived from, *e.g.*, algae, municipal waste, used frying oil etc.). Among these types, first-generation biofuels from agricultural commodities are modelled fully endogenously in the model, while the production of second-generation and other biofuels enter as exogenous variables. Implications of second-generation biofuels on agricultural markets, however, are reflected through endogenous links to crop area, crop revenues and the feed-livestock links.

Production of biofuels is generally represented by the production capacity and the capacity use rate. Production capacity growth is modelled as a function of the net revenues from biofuel production, *i.e.* the difference between the output value (biofuel price and any subsidies directly linked to biofuel production) and the production costs per unit of biofuels (net of the value of by-products). Capacity growth generally responds to these net revenues with several time lags, given the time required to plan and construct new facilities. The capacity use rate, in contrast, depends on net revenues not considering capital fixed costs, and responds to market signals without lags. Generally, biofuel production is modelled separately for individual feedstocks and added up for the total production of each type where several feedstocks are used for a type of biofuels in a given country.

Second-generation biofuel production from dedicated biomass production partly competes with the production of commodities for other usages. In consequence, the area required is estimated from the production quantity, and a share of this area is deduced from the land used for agricultural market commodities. In contrast, second-generation biofuel production from crop residues complements the production of agricultural commodities. The added value therefore is taken into consideration in the calculation of the crop revenues and hence in the crop allocation system.

By-products from biofuel production form an integral element in the production costs. At the same time, however, some of these by-products go back into the agricultural production process. In particular, distillers grains, a by-product from grain based ethanol production, deserves special attention. As the market for distillers grains are not represented in Aglink (and a full market representation for distillers grains is not intended), a market price for distillers grains is derived from the prices for oilmeals and coarse grains, the two main feed products distillers grains can replace in the feed ratios. For the two main livestock types – ruminant and non-ruminant livestock – the feed cost index then is modified to take into account the different use of distillers' grains in the ratios for these animals. Finally, the feed use of coarse grains and of oilmeals is adjusted for the use of distillers' grains.

The demand for ethanol generally is split up into three components: an additive component where ethanol replaces other (chemical) additives in the blend with gasoline; a low-level blend (or fuel extender) component where the lower energy content in ethanol compared to gasoline is offset by superior other qualities (such as the higher oxygen content and octane number); and ethanol as a neat fuel consumed by specifically modified vehicles, so-called flex-fuel vehicles. These three demand components are explicitly taken into account in estimating the ethanol demand, all considering the price ratio between ethanol and fossil gasoline as the driving variable. Biodiesel use, in contrast, is modelled as a simple equation depending on the price ratio between biodiesel and fossil diesel. Where biofuel mandates exist and data are available, these are modeled as minimum biofuel shares, and the link between biofuel demand and the price ratio is cut unless demand exceeds the specified minimum. [1]

Finally, markets are cleared by a net trade position residual from domestic supply and demand, with the domestic prices for biofuels depending on their respective world prices taking into account import tariffs in the net import situation. World prices for ethanol and biodiesel clear the markets on the global level.

The following sections describe the modelling approach in greater detail.

Biofuel production

First-generation biofuels from agricultural commodities

Net Cost estimates (NC) for alternative biofuels as modelled in the 2006 report, but separate for different technologies / feedstocks, based on actual prices without support linked to biofuels. Where relevant, revenues for by-products should explicitly account for Distillers Dried Grains (DDG):

$$\begin{aligned} NC^{i,j}_{r,t} &= \alpha^{i,j}_{r,t} * PP^{i}_{r,t} \\ &\quad + \beta 0^{i,j}_{r,t} + \beta^{i,j}_{r,t} * XP^{OIL}_{t} * XR_{r,t} \\ &\quad + \gamma 0^{i,j}_{r,t} + \gamma 1^{i,j}_{r,t} \\ &\quad - \delta^{i,j,DDG}_{r,t} * WP^{DDG}_{r,t} - \delta^{i,j,EF}_{r,t} * PP^{CG}_{r,t} - \delta^{i,j,PF}_{r,t} * PP^{OM}_{r,t} - \delta^{i,j,OBP}_{r,t} \end{aligned}$$

with

i	commodity index for feedstocks
j	product index for biofuels
r	region index
t	time index
NC	net costs of biofuel production (average, LC/hl)
PP,WP	domestic prices (producer, wholesale, LC/hl)
XP^{OIL}	world crude oil price (USD/barrel)
XR	exchange rate (LC/USD)
DDG	distillers dried grains
EF	energy-rich feed
PF	protein-rich feed
CG	coarse grains
OM	oilseed meals
OBP	other by-products
α,β,δ	coefficients
γ0	capital cost element in production costs
γ1	other exogenous elements in production costs (operation and maintenance costs)

In addition, Variable Net Costs (VNC) exclude fixed costs, *i.e.* capital costs which are not relevant for production decision based on existing capacities:

$$\begin{aligned} VNC^{i,j}_{r,t} &= \alpha^{i,j}_{r,t} * PP^{i}_{r,t} \\ &\quad + \beta 0^{i,j}_{r,t} + \beta^{i,j}_{r,t} * XP^{OIL}_{t} * XR_{r,t} \\ &\quad + \gamma 1^{i,j}_{r,t} \\ &\quad - \delta^{i,j,DDG}_{r,t} * WP^{DDG}_{r,t} - \delta^{i,j,EF}_{r,t} * PP^{CG}_{r,t} - \delta^{i,j,PF}_{r,t} * PP^{OM}_{r,t} - \delta^{i,j,OBP}_{r,t} \end{aligned}$$

with

VNC	variable net costs (average, LC/hl)

Growth in Production Capacities (QPC) should depend on returns over investments expected for biofuel production facilities, which would be modelled as returns (including support directly related to production quantities) net of net production costs, relative to capital costs. Given that it takes about 18 months to set up a biofuel plant, and that expected returns largely depend on past returns, the lag structure needs to take into account t-1 till t-4. As it is possible to speed up the building process to some degree, the current period also enters but the coefficient would be small. The size of the parameters for different lags are, therefore, likely to be ordered as follows: t-2 > t-1 > t-3 > t-4 > t. We assume that biofuel producers are aware of policy changes and take them into account immediately. Market developments are seen as volatile, however, and hence more than just the available year's data are taken into account in investment decisions.

The US could provide sufficient data to back a general capacity building function, but US data need to be scaled by appropriate measures to make them comparable to other countries2. A proxy for total industry investment, corrected for foreign direct investment, needs to be identified.

$$QPC_{r,t}^{i,j} = \begin{pmatrix} QPC_{r,t-1}^{i,j} + \chi_r^{i,j} \\ +\phi0_r^{i,j} * \left(WP_{r,t}^{j} + DP_{r,t}^{i,j} - NC_{r,t}^{i,j}\right) \Big/ \gamma0_{r,t}^{i,j} * INV_{r,t} \Big/ GDPD_{r,t} \\ +\phi1_r^{i,j} * \left(WP_{r,t-1}^{j} + DP_{r,t-1}^{i,j} - NC_{r,t-1}^{i,j}\right) \Big/ \gamma0_{r,t-1}^{i,j} * INV_{r,t-1} \Big/ GDPD_{r,t-1} \\ +\phi2_r^{i,j} * \left(WP_{r,t-2}^{j} + DP_{r,t-2}^{i,j} - NC_{r,t-2}^{i,j}\right) \Big/ \gamma0_{r,t-2}^{i,j} * INV_{r,t-2} \Big/ GDPD_{r,t-2} \\ +\phi3_r^{i,j} * \left(WP_{r,t-3}^{j} + DP_{r,t-3}^{i,j} - NC_{r,t-3}^{i,j}\right) \Big/ \gamma0_{r,t-3}^{i,j} * INV_{r,t-3} \Big/ GDPD_{r,t-3} \\ +\phi4_r^{i,j} * \left(WP_{r,t-4}^{j} + DP_{r,t-4}^{i,j} - NC_{r,t-4}^{i,j}\right) \Big/ \gamma0_{r,t-4}^{i,j} * INV_{r,t-4} \Big/ GDPD_{r,t-4} \end{pmatrix} * R.QPC_{r,t}^{i,j}$$

with

QPC biofuel production capacity

DP direct support for biofuel output

INV available investment capital in country r (including foreign direct investment)

GDPD GDP deflator

Capacity Use Rates (QPR) will depend on variable net costs rather than total net costs as explanatory variable:

$$QPR_{r,t}^{j} = QPRL_{r,t}^{j} + \frac{QPRU_{r,t}^{j} - QPRL_{r,t}^{j}}{1 + LOGA_r^{j} * e^{\left(LOGB_r^{j} * \left(VNC_{r,t}^{i,j} \Big/ \left(WP_{r,t}^{j} + DP_{r,t}^{i,j}\right)\right)\right)}}$$

with

QPR biofuel production capacity use rate

QPRL, QPRU lower and upper bounds for the use rate

LOGA, LOGB parameters in logistic function

Total production of biofuels will be discussed after the modelling of second-generation fuels.

Second-generation biofuels

Second-generation biofuels can be categorised in three groups, depending on their links to agricultural production. Ethanol and Fischer-Tropsch fuels can be produced either from dedicated crops produced in agricultural production systems (*e.g.* from grasses such as miscanthus or switchgrass or from fast-growing trees such as willow, poplar or eucalyptus), from agricultural residues (*e.g.* straw, stover etc.), or from biomass not produced in agricultural systems (*e.g.* from forestry, household waste, algae etc.). Consistent with their different relationships to agricultural production systems, these three groups of biofuels need to be modelled differently in the agricultural market model Aglink-Cosimo. Given that data on second-generation biofuels (production, feedstocks, costs etc.) are even more difficult to find than on first-generation fuels, the representation of any kind of second-generation biofuels will need to be more ad hoc and of a less sophisticated nature.[3]

Second-generation biofuels from dedicated crops

Dedicated crops that provide cellulose for ethanol, or biomass for Fischer-Tropsch synthesis fuels, are often, but not always, produced on land that alternatively could be used for food or feed production, and hence have the potential to negatively impact the supply of those products. Given the uncertainties related to second-generation biofuel technologies and economic, the less than perfect data situation, and the wide range of production and conversion technologies, we propose a relatively simple model representation where ethanol and Fischer-Tropsch-Diesel are produced directly on the agricultural land, *i.e.* the feedstock production, transport, and conversion to biofuels are combined in a single, synthetic production process. While this simplification obviously ignores the large variability of production and conversion systems, and assumes that the biomass produced in one country is also converted in that same country, it allows for a relatively generic specification in the model that, in addition, could also include other forms of bioenergy sourced from agricultural biomass and/or production of first-generation biofuels from feedstocks not covered by the model (*e.g.* jatropha) in a similar manner. Depending on the country in question, parameters would differ and thus allow for a differentiation according to the relative advantages of individual production systems in alternative regions.

Net production costs consist of biomass costs, transport costs and conversion costs, and thus can be represented as follows:

$$NC_{r,t}^{i,j} = \alpha_{r,t}^{i,j} * \left(PC_{r,t}^{i} + TC_{r,t}^{i}\right) + CC_{r,t}^{i,j}$$

Where:

$$PC_{r,t}^{i} = MC_{r,t}^{i} + LC_{r,t}^{i} + LR_{r,t} \Big/ YLD_{r,t}^{i}$$

$$TC_{r,t}^{i} = TC_{r,t}^{i,spec} + \sum_{ts}\left(TC_{r,t,ts}^{i,lc} + dist_{r,t,ts}^{i} * \left(TC_{r,t,ts}^{i,ec} + TC_{r,t,ts}^{i,mc}\right)\right)$$

$$CC_{r,t}^{i,j} = \gamma 0_{r,t}^{i,j} + \gamma 1_{r,t}^{i,j} - \delta_{r,t}^{i,j,OBP}$$

With:

NC	net production costs (average, LC/hl)
α	conversion rate, t of biomass per hl of biofuel
PC	biomass production costs (LC/t)
TC	biomass transport costs (LC/t)
CC	conversion costs (LC/hl)
MC	capital and management costs of biomass production (LC/t)
LC	labour costs of biomass production (LC/t)
LR	land rent (LC/ha)
YLD	biomass yield (t/ha)
TC^{spec}	specific costs of pelletising (LC/t)
TC^{lc}	loading/unloading costs (LC/t)
dist	distance, km
TC^{ec}	energy costs of transportation (LC/km/t)
TC^{mc}	management costs of transportation (LC/km/t)
$\gamma 0$	capital cost element in production costs
$\gamma 1$	other exogenous elements in production costs (operation and maintenance costs)
δ^{OBP}	value of by-products not specified
i	biomass type (BME: biomass for cellulosic ethanol; BMD: biomass for FT-Diesel)

above, land rents are obviously crucial for the interaction between second-generation biofuel production and agricultural markets. In future it will therefore be important to endogenise this cost element.

The total area required for the biomass production related to exogenously assumed biofuel quantities[4] is calculated from exogenously assumed yields – in the case of multiple biofuels produced from a given type of biomass these are summed up:

$$AH_{r,t}^{i} = \sum_{j} \left(\alpha_{r,t}^{i,j} * QP_{r,t}^{i,j} \right) \Big/ YLD_{r,t}^{i}$$

As biomass for biofuel production often is produced on land not suitable for food production, the food area required is calculated from an exogenous share which depends on the type of biomass produced. This factor also depends on policy decisions, such as the permission to use set-aside land:

$$AH_{r,t}^{i,eff} = AH_{r,t}^{i} * AH_{r,t}^{i,shr}$$

The area used for individual food crops is then reduced proportionally to the alternative use for biomass production[5]:

$$AH_{r,t}^{c} = \exp\left(const + f\left(RH_{r,t-1}^{c'}\right) + \varepsilon_{r}^{c,BM} * \ln\left(\frac{\left(\sum_{c'} AH_{r,t-1}^{c'} + \sum_{i} AH_{r,t-1}^{i,eff} - \sum_{i} AH_{r,t}^{i,eff} \right)}{\sum_{c'} AH_{r,t-1}^{c'} + \sum_{i} AH_{r,t-1}^{i,eff}} \right) \right)$$

With
c crop index [WT, CG, OS]
The elasticities with respect to the effective biomass area reflect the different displacement of different crops by biomass for energy. They need to be calibrated such that, in the base period:

$$\frac{\sum_c \varepsilon_r^{c,BM} * AH_r^c}{\sum_c AH_r^c} = 1$$

Second-generation biofuels from agricultural residues

Agricultural residues such as straw or stover can be used for the production of ethanol via gasification, or of other biofuels via the Fischer-Tropsch synthesis. Its modelling has to be different to that of biofuels from dedicated biomass production as, in general, no or little additional costs occur with the production of that biomass (there may be additional costs associated with harvesting). In contrast, transport costs may be higher than in the case of dedicated biomass production given the lower yield per hectare and hence the larger distances on average between the production area and the processing plant.

However, a minimum price for the agricultural residues can be defined by the opportunity costs of the biomass, such as its fertiliser value, possibly adjusted by the difference between the costs for harvesting the biomass and those for applying the fertiliser. Opportunity costs may higher if other uses prevail, such as animal bedding, which in a large scale is more common in developing countries than in developed countries today. Finally, the opportunity costs would increase significantly as the removal of organic matter would threaten the fertility of the soil, which in general can be assumed not to be relevant as long as at least two thirds of the residues remain on the farm.[6] ,[7].

An additional difference to biofuels from dedicated biomass production is that, as a co-product, the revenues for agricultural residues will increase incentives for the production of the main product.

In consequence, costs of biofuel production are calculated on the basis of the fertiliser value of the crop residues – this value should increase once the threshold value of one third of the residues is used for biofuels:

$$NC_{r,t}^{RES,j} = \alpha_{r,t}^{RES,j} * \left(FV_{r,t}^{RES} + SV_{r,t}^{RES} + TC_{r,t}^{RES}\right) + CC_{r,t}^{RES,j}$$

$$SV_{r,t}^{RES} = \begin{bmatrix} \text{if } \dfrac{BF_{r,t}^{RES}}{QP_{r,t}^{WT} + QP_{r,t}^{CG}} < \dfrac{1}{3} \text{ then } 0 \\ \text{else } SF_{r,t} * \left(\dfrac{3 * BF_{r,t}^{RES}}{QP_{r,t}^{WT} + QP_{r,t}^{CG}} - 1\right)^2 \end{bmatrix}$$

$$CC_{r,t}^{RES,j} = \gamma 0_{r,t}^{RES,j} + \gamma 1_{r,t}^{RES,j} - \delta_{r,t}^{RES,j,OBP}$$

Where:

RES	crop residues
FV	fertiliser value per tonne of crop residues
SV	soil quality value of crop residues
SF	soil quality factor
BF^{RES}	use of crop residues for biofuels
QP^{WT}, QP^{CG}	production quantity of wheat, coarse grains

The soil quality factor will need to be set to a rather large number to prevent the residue use from becoming significantly greater than a third of residue production.

As farmers will engage in harvesting the additional biomass only if the additional revenues exceed the fertiliser value, it is assumed that the profit margin, per tonne of biomass, is split equally between the agricultural producer and the processing plant. In consequence, 50% of the margin add value to the cereal production on farm[8], with its total effect again depending on the exogenously assumed production of the biofuels:

$$RV_{r,t}^{RES,j} = 0.5 * \left(WP_{r,t}^{j} + DP_{r,t}^{RES,j} - NC_{r,t}^{RES,j} \right) \Big/ \alpha_{r,t}^{RES,j}$$

$$BF_{r,t}^{RES,j} = QP_{r,t}^{RES,j} \Big/ \alpha_{r,t}^{RES,j}$$

With:

RV	residue value per tonne of biomass
$BF^{RES,j}$	use of crop residues for biofuel type j

Both residue value and the residue quantity used for biofuel production can be aggregated across biofuel types:

$$BF_{r,t}^{RES} = \sum_{j} BF_{r,t}^{RES,j}$$

$$RV_{r,t}^{RES} = \left. \sum_{j} BF_{r,t}^{RES,j} * RV_{r,t}^{RES,j} \middle/ BF_{r,t}^{RES} \right.$$

Assuming that the share of residues used for biofuel production is the same across cereal types, net returns of crop production can be expressed as

$$RH_{r,t}^{i} = f\left(YLD_{r}^{i}, PP_{r,t}^{i} + RV_{r,t}^{RES} * \frac{BF_{r,t}^{RES}}{AH_{r,t}^{WT} + AH_{r,t}^{CG}} \right)$$

Biofuels from non-agricultural sources

Biofuels from non-agricultural sources include biodiesel from used cooking oils, synthesis fuels (BTL) from municipal wastes or algae, ethanol from forest residues and wood chips, and a number of other forms of organic matter which have no or very little link to agricultural production. While their production processes do not affect agriculture directly, this additional supply impacts on biofuel markets and can hence have indirect effects on biofuel prices and agricultural biomass use. Biofuels from non-agricultural sources are therefore included exogenously in the model for completeness reasons.

$$QP^{nonag,j}_{r,t} = \overline{QP^{nonag,j}_{r,t}}$$

Total biofuel production

Total production of any type of biofuel (ethanol and biodiesel) will be the simple sum of the individual quantities by feedstock, with first-generation fuels depending on the Capacity Use Rate and the Capacity itself. As the Capacity is for the end year point in time, the average of t and t-1 should be taken into account:

$$QP^{j}_{r,t} = \sum_{i} QPS^{i,j}_{r,t} * \left(QPC^{i,j}_{r,t} + QPC^{i,j}_{r,t-1}\right)\Big/2 + QP^{BMj,j}_{r,t} + QP^{RES,j}_{r,t} + QP^{nonag,j}_{r,t}$$

By-products

A number of by-products are relevant in the context of biofuel markets. While oilseed meals are directly linked to the oilseed crush (with the vegetable oil being used partly for the production of biodiesel) and have been covered by the model before, distillers' grains, either in liquid or in dried form (DDG) deserve particular attention. DDG is co-produced with cereal-based ethanol in the dry milling process and increasingly important for animal feed markets in North America and Europe.

Price of DDG

Based on US data, the link between the price of DDG and the prices of maize and soyabean meal is not that strong: using wholesale prices for DDG and soyabean meal, market prices for maize and annual data from 1981 to 2006 shows an R² of only 57%. The quantity of maize used for the production of ethanol – as a proxi for the DDG quantity produced – proves to be an important explanatory variable: the following equation has an R² of 85%:

$$WP^{USA}_{DDG,t} = 204.8869 + 0.384775 * WP^{USA}_{SBM,t} + 0.545321 * MP^{USA}_{MA,t} - 22.09 * \ln\left(MABF^{USA}_{t}\right)$$

(t-stats: 5.52 5.16 4.21 6.12)

with:

WP	wholesale price, USD per metric tonne
MP	market price, USD per metric tonne
DDG	distillers dried grains, Laurenceburg, Indiana, marketing year data (Oct-Sep)
SBM	soyabean meal, 44% protein[9], Central Illinois, marketing year data (Oct-Sep)
MA	maize, No. 2 Yellow, Central Illinois, marketing year data (Sep-Aug)
MABF	maize use in biofuel (ethanol) production, 1 000 metric tonnes, marketing year data (Sep-Aug)

Using the quantity of maize used for the production of ethanol divided by the ruminant production, or alternatively the beef production, yields only lower coefficients of determination at around 83%[10].

Feed-cost index

The model already contains share estimates for feed used in the ruminant versus non-ruminant sectors. DDG, however, would be shared differently as ruminants can digest this feed at higher ratios than non-ruminants. In addition, DDG replaces coarse grains and oil meals at different rates across livestock types. These replacement quantities would be calculated as follows:

$$FE_{DDG}^{RU,CG} = QP_{DDG} * SHR_{DDG}^{RU} * SHR_{DDG}^{RU,CG}$$

with

$FE_{DDG}^{RU,CG}$	quantity of DDG replacing coarse grains in ruminant livestock feed ratio
SHR_{DDG}^{RU}	share of domestic DDG feed to ruminant livestock
$SHR_{DDG}^{RU,CG}$	amount of coarse grains replaced by one tonne of DDG in ruminant feed ratio

In consequence, a – lower – blended coarse grains price for feed in ruminant livestock can be derived from the CG and DDG prices and the respective feed quantities:

$$PP_{CG}^{bld,RU} = \frac{PP_{CG} * \left(\left(FE_{CG} + FE_{DDG}^{RU,CG} + FE_{DDG}^{NR,CG}\right) * PSH^{RU} - FE_{DDG}^{RU,CG}\right) + WP_{DDG} * FE_{DDG}^{RU,CG}}{\left(\left(FE_{CG} + FE_{DDG}^{RU,CG} + FE_{DDG}^{NR,CG}\right) * PSH^{RU} - FE_{DDG}^{RU,CG}\right) + FE_{DDG}^{RU,CG}}$$

with:
PSH^{RU} share coefficient denoting the share of ruminant livestock in feed demand;
$= 1 - PSH^{NR}$

Similar equations would define blended feed prices for coarse grains in non-ruminants, and for oil meals in both ruminants and non-ruminants.

For the purpose of defining livestock-type specific feed-cost indices, blended feed quantities would be defined in a straight-forward manner:

$$FE_{CG}^{bld,RU} = \left(FE_{CG} + FE_{DDG}^{RU,CG} + FE_{DDG}^{NR,CG}\right) * PSH^{RU}$$

For wheat, the blended feed use is simply calculated from the livestock type share alone, while the blended price remains unchanged:

$$FE_{WT}^{bld,RU} = FE_{WT} * PSH^{RU}$$

$$PP_{WT}^{bld,RU} = PP_{WT}$$

With that, the two feed cost indices can be constructed in line with the original one:

$$\ln\left(FECI_{RU}\right) = \frac{\sum\limits_{i=WT,CG,OM} FE_i^{bld,RU} * PP_i^{bld,RU} * \ln\left(PP_i^{bld,RU}\right)}{\sum\limits_{i=WT,CG,OM} FE_i^{bld,RU} * PP_i^{bld,RU}}$$

Feed use of coarse grains, oil meals

Feed use of individual commodities is modelled on a national level rather than for individual livestock types. An average blended feed price is there calculated using the livestock type shares:

$$PP_i^{bld} = PSH^{NR} * PP_i^{bld,NR} + \left(1 - PSH^{NR}\right) * PP_i^{bld,RU}$$

As the blended coarse grains price declines with increased ddg use, the comparative profitability of feeding the coarse grain – ddg blend increases relative to other feed commodities, notably wheat:

$$\ln\left(FE_{CG} + FE_{DDG}\right) = f\left(\left(PP_i^{bld} \middle| i = WT, CG, OM\right), \left(QP_i \middle| i = RU, NR\right)\right)$$

Where

$$FE_{DDG} = QP_{DDG} * \left(SHR_{DDG}^{RU} * SHR_{DDG}^{RU,CG} + SHR_{DDG}^{NR} * SHR_{DDG}^{NR,CG}\right)$$

Effects of increased ethanol and DDG production on feed use

In consequence, an increased production of grain-based ethanol has the following implications for cereal feed use:

- With higher demand for cereals, prices increase, and feed use of cereals declines
- Higher feed costs also reduce livestock production, so again feed use of cereals declines
- Increased availability of DDG, marketed at a discount compared to feed cereals, reduces the price of the CG-DDG blend, which partly offsets the higher feed costs and hence the reduction in livestock production.
- As the blended price of CG-DDG declines, the feed share of the CG-DDG blend increases at the cost of other feed commodities, particularly wheat.

Biofuel demand

Price ratios driving biofuel demand

Generally speaking, demand of biofuels, expressed as a share of total demand for a given fuel type (*i.e.* gasoline and ethanol, or diesel and biodiesel) responds to the market price of the biofuel relative to the price of its fossil competitor. All prices are calculated at the retail level and denominated in LC/hl of fuel, *i.e.* no conversion is being made to account for the different energy content of the fuels.

Ethanol

Given the properties of ethanol relative to gasoline, the use of fuel ethanol can be separated in three broad groups: Ethanol as an additive, ethanol in low-level blends, and ethanol as a neat fuel. The use of biofuels generally responds to changes in the market retail prices rather than wholesale prices – the difference being explained by any remaining fuel taxes and the retail margin:

$$RP_{r,t}^{j} = WP_{r,t}^{j} + TAX_{r,t}^{j} + MAR_{r,t}^{j}$$

Ethanol as an additive

If used as an additive, ethanol does not compete with gasoline, but with other additives, to the degree these are (legally and economically) available. In the simplest form, if no alternative additive is available, the ethanol use is a fixed share of the total gasoline use. In other cases, ethanol will replace other additives as its price approaches or falls below the price of the substitute. As most additives are crude oil based products, this trigger price will be related to that of gasoline. As in the case of low-level blends and neat fuels, we use a sine function to mirror the substitution process:

$$QCS_{ET}^{ADD} = \left\{ \begin{array}{l} \text{if no alternative}: BLD_{ET,GAS}^{ADD,GE} \\ \text{else if } \mathrm{PR}_{\mathrm{ET,Gas}} > MP_{Add}^{spl} + MP_{Add}^{spr} : 0 \\ \text{else if } \mathrm{PR}_{\mathrm{ET,Gas}} < MP_{Add}^{spl} - MP_{Add}^{spr} : BLD_{ET,GAS}^{ADD,GE} \\ \text{else}: \left(\sin\left(\dfrac{\left(\mathrm{PR}_{\mathrm{ET,Gas}} - MP_{Add}^{spl} + 2 * MP_{Add}^{spr}\right) * \pi}{2 * MP_{Add}^{spr}} \right) \Big/ 2 + 0.5 \right) * BLD_{ET,GAS}^{ADD,GE} \end{array} \right\}$$

with:

QCS_{ET}^{ADD}	Ethanol share in gasoline as an additive, energy equivalent
$BLD_{ET,GAS}^{ADD,GE}$	Additive share in gasoline
PR_{ET}^{Gas}	Price ratio between ethanol and gasoline, market prices
MP_{Add}^{spl}	Price of additive relative to gasoline
MP_{Add}^{spr}	Price spread in which substitution for additives occurs

Ethanol in low-level blends

Low-level blends are characterised by the fact that the lower energy content of ethanol compared to gasoline is offset by the higher octane number and oxygen content. In some cases, ethanol may additionally be preferred by consumers for non-economic reasons (*i.e.* due to its image of a "green" fuel). In consequence, ethanol competes with gasoline without a price discount (and in fact may even receive a premium over gasoline on a per litre basis). As the share of ethanol increases, the lower energy content becomes more relevant, resulting in a price discount on a per litre basis. In contrast to the case of high-level blends or neat fuels, the decision about low-level blends is taken by the fuel blenders and distributors rather than the final consumers. In any case, mandatory blending requirements represent a lower bound for the amount of ethanol sold in low-level blends.

As above, we use sine functions to represent the substitution process:

$$QCS_{ET}^{LBLD} = \max\left(QCS_{ET}^{OBL} - QCS_{ET}^{ADD},\ \left\{ \begin{array}{l} \text{if } \mathrm{PR}_{\mathrm{ET,Gas}} > MP_{ET}^{prem} : 0 \\ \text{else if } \mathrm{PR}_{\mathrm{ET,Gas}} < ERAT_{ET,Gas} : QCS_{ET}^{Limit} - QCS_{ET}^{ADD} \\ \text{else} : \dfrac{\sin\left(\dfrac{\left(2 * \mathrm{PR}_{\mathrm{ET,Gas}} + MP_{ET}^{prem} - 3 * ERAT_{ET,Gas}\right) * \pi}{2 * \left(MP_{ET}^{prem} - ERAT_{ET,Gas}\right)} \right) + 1}{2} * \left(QCS_{ET}^{Limit} - QCS_{ET}^{ADD}\right) \end{array} \right\} \right)$$

with:

QCS_{ET}^{LBLD}	Ethanol share in gasoline in a low level blend, energy equivalent
QCS_{ET}^{OBL}	Blending obligation, share, energy equivalent
MP_{ET}^{prem}	Maximum premium price of ethanol in low-level blends, relative to gasoline price, ratio
$ERAT_{ET,Gas}$	Energy content ratio between ethanol and gasoline
QCS_{ET}^{Limit}	Upper limit for ethanol in low-level blends, share

Ethanol as neat fuel

Ethanol as a neat fuel can be consumed only by holders of dedicated cars. Today, the share of vehicles that can run on ethanol only is minuscule. Instead, flexi-fuel vehicles (FFVs) provide the option to be run on pure ethanol (or any high-level blend offered by the industry), pure gasoline (or any low-level blend offered as the standard blend) or any mixture of the two. It can be expected that, after some adjustments, FFV-owners will chose ethanol (or the high-level blend) whenever its price falls below the gasoline price adjusted for the lower energy content. If the ethanol price is higher than that, FFV-owners will chose gasoline (or the low-level blend). A substitution process can be expected to take place at ethanol prices close to that level, which, again, is represented by sine functions:

$$QCS_{ET}^{FFV} = \left\{ \begin{array}{l} \text{if } \mathrm{PR}_{\mathrm{ET,Gas}} > ERAT_{ET,Gas} + MP_{FFV}^{spr} \;:0 \\ \text{else if } \mathrm{PR}_{\mathrm{ET,Gas}} < ERAT_{ET,Gas} - MP_{FFV}^{spr} \;:1 \\ \text{else}: \left(\sin\left(\frac{\left(\mathrm{PR}_{\mathrm{ET,Gas}} - ERAT_{ET,Gas} + 2 * MP_{FFV}^{spr}\right) * \pi}{2 * MP_{FFV}^{spr}} \right) \Big/ 2 + 0.5 \right) \end{array} \right\}$$

$$* FFV * QCS_{ET}^{HBLD} * \left(1 - QCS_{ET}^{ADD} - QCS_{ET}^{LBLD}\right)$$

with:

QCS_{ET}^{FFV}	Ethanol used as neat fuel by flexi-fuel vehicles, share, energy equivalent
MP_{FFV}^{spr}	Price spread in which substitution for FFVs occurs
FFV	Share of FFVs in total vehicle fleet – changing exogenously over time
QCS_{ET}^{HBLD}	Ethanol share in high-level blends used in FFVs, energy equivalent

It should be noted that many of these variables – and in particular the share of FFVs in the total vehicle fleet, are likely to evolve over time – a time index has been omitted for readability, but needs to be taken into account in the modelling.

Non-fuel use of ethanol

Ethanol is a product that is widely used in a large number of sectors, most notably in beverages and the chemical and pharmaceutical industry. As a priori ethanol for fuel use cannot be differentiated from ethanol destined for other utilisations, the latter need to be taken into account as well.

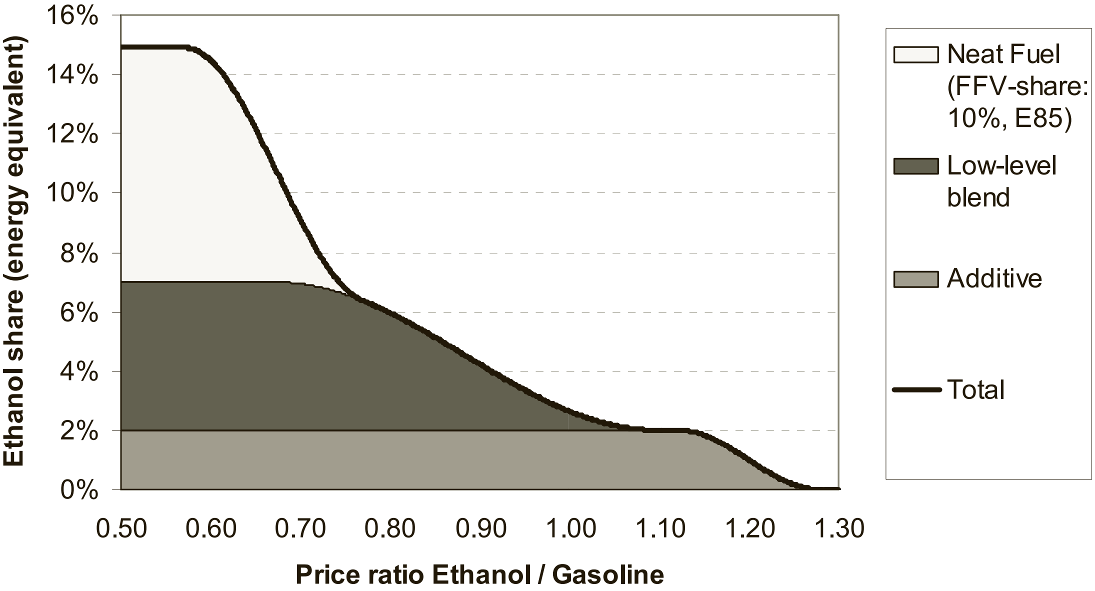
$$QC_{ET}^{other} = \overline{QC_{ET}^{other}}$$

Total ethanol use

The total share of ethanol in spark-ingestion vehicles is the simple sum of the three elements presented above:

$$QCS_{ET} = QCS_{ET}^{ADD} + QCS_{ET}^{LBLD} + QCS_{ET}^{FFV}$$

Annex Figure A.1. Graphical representation of ethanol demand as a function of the ethanol-gasoline price ratio at a given point in time



As these shares are on an energy basis, the ethanol quantity used can be calculated based on the total use of gasoline and equivalent fuels, and the relative energy content of ethanol:

$$QC_{ET} = \frac{QCS_{ET} * QC_{Gas}}{ERAT_{ET,Gas}} + QC_{ET}^{other}$$

Biodiesel

There is no such thing as FFVs using biodiesel, and there also is not any ‘additive’ effect of low-level blends in fossil diesel fuel. However, most vehicles can stand only low-level blends without modification. Within those bands, vehicle owners largely rely on the blending industries’ decisions on the biodiesel blending rates – which themselves depend on legal conditions and standards. In consequence, a simpler representation of biodiesel use is deployed:

$$\ln\left(QCS_{BD}\right) = \max\left\{\begin{matrix} QCS_{BD}^{OBL}, \\ const + \sum_{n=0}^{2} \alpha^{n} * \ln\left(PR_{BD,Die}^{t-n}\right) + \beta * \ln(t) \end{matrix}\right\}$$

Again, the absolute consumption of biodiesel would be based on the total use of diesel fuels:

$$QC_{BD} = \frac{QCS_{BD} * QC_{Die}}{ERAT_{BD,Die}}$$

Trade

The model for biofuels represents net trade only and abstracts from stock changes:

$$NT_{r,t}^{j} = QP_{r,t}^{j} - QC_{r,t}^{j}$$

Domestic price determination

Domestic prices are assumed to be determined by the world price[11], including, in the case of (substantial) imports, any tariffs the country may impose. To represent the shift of the price regime in a the case of a change of net trade position, a logistic function is used that describes the price differential between domestic and world price relative to the applied tariff (including natural barriers if any) as a function of the net trade position relative to the sum of domestic production and consumption as follows:

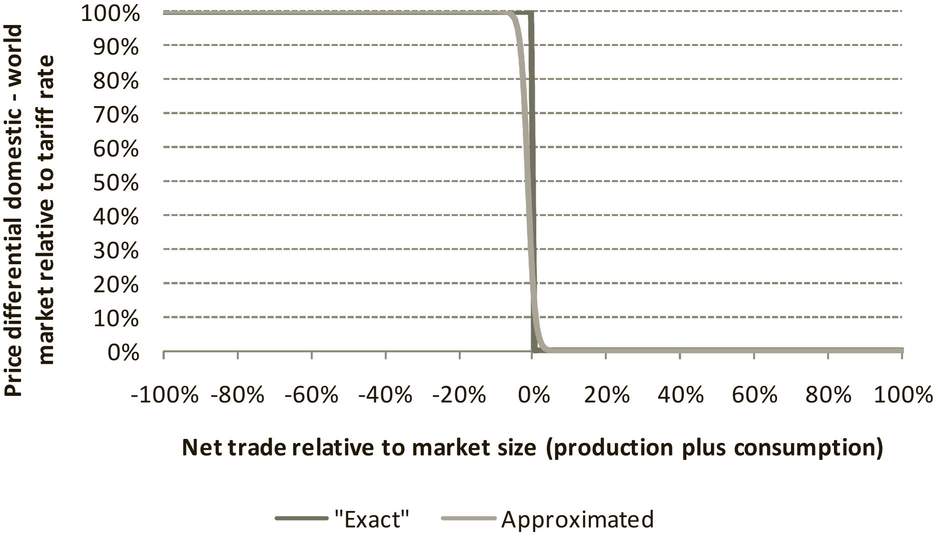
$$\frac{WP_{r,t}^{j} - XP_{t}^{j}}{XP_{t}^{j} * TARA_{t}^{j} + TARS_{t}^{j}} = \frac{a}{1 + b * c^{-\left(\frac{NT_{r,t}^{j}}{QP_{r,t}^{j} + QC_{r,t}^{j}}\right)}}$$

The parameters are chosen such that

- The range of the resulting relative price differentials is [0 - 1], *i.e.*, a=1
- The function is strictly monotonously decreasing with falling net imports and growing net exports, *i.e.*, 0<c<1
- The range of net trade positions with the relative price differential being significantly different from both 0 and 1 is narrow, *i.e.*, c is small in value
- The function is squewed to the left to avoid import tariffs from being relevant in (substantially) net exporting countries, *i.e.*, b>1

Parameter values used in this analysis are b = 4 and $c = 10^{-45}$. While the choice of these parameters is somewhat arbitrary, the values represent a compromise between the need to closely approximate the real relationship (i.e., strong pass-through of the tariff in a net import situation, no pass-through in a net export situation) on the one hand, and of ensuring smooth and plausible model responses on the other. With these parameters, the relationship between a country's net trade position and its price link to world markets can be represented by the following figure:

Annex Figure A.2. Graphical representation of the price link between domestic and world markets as a function of the net trade position



Global price determination

A unique world price for each type of biofuels is used to clear international markets, *i.e.* to ensure that global net exports equal global net imports:

$$XP_t^j = XP_t^j + \sum_r NT_{r,t}^j$$

Notes

1. For the EU, mandated biofuel use and consumption in Member States without mandates but providing tax concessions are modelled separately to account for the regional differences within the Union.

2. The comparability to other countries obviously depends on a range of factors, including, among others, similarities in capital markets and investor behaviour. While scaling by the proxy for industry investment account for such factors to some degree, other adjustments may be necessary in the parameterisation of the capacity functions of other countries.

3. Technical parameters on second-generation biofuel production were obtained from Dornburg *et al*.

4. Estimating the supply response of second-generation biofuels remains a major research topic that needs to be addressed once commercial data on such an industry becomes available.

5. Note that for simplicity, the crop areas of the preceding period are used to estimate the share of biomass land

6. It is assumed that per tonne of cereals one tonne of residues are produced on average. This assumption obviously abstracts from important differences across cereal types and regions.

7. Note that, considering the stylised model of equally sized circles around biofuel plants, only a maximum of some 90% ($\pi/\sqrt{12}$) can be used for second-generation biofuels from agricultural residues. In consequence, the one third of the residues maximum available for biofuels would reduce to 30%. Given the approximative character of all these calculations we abstract from this detail.

8. Note that in principle, residues from other crops can be used for biofuel production as well. This principle possibility is ignored at this point, as research under way suggests that cellulose-based ethanol from crop residues would be mostly from straw and stover.

9. Prices for soyabean meal 44% protein (SBM44) are reported until 2001/02 only. Data for 2002/03 to 2006/07 are calculated from prices reported for soyabean meal, 49-50% protein, Illinois points (SBM50), based on the equation SBM44 = -3.43176 [3.07] + 0.953679 [184.5] * SBM50 (estimated on monthly data, $R^2 = 99.34\%$, t-statistics in brackets).

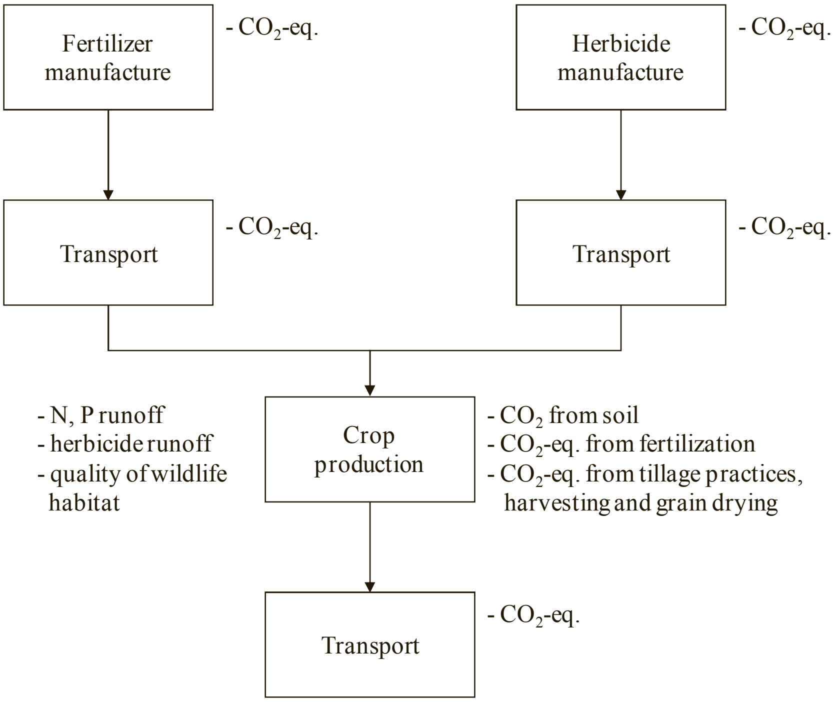
10. Given that statistics on DDG markets are less readily available for other countries, however, the ruminant production in the base period can help to scale the US equation to those of other countries.

11. The exception is the Canadian ethanol price which is linked directly to the US price given the close link between US producing and Canadian demand areas.

Annex B.

Environmental Effects Covered in the SAPIM Application

Annex Figure B.1. Environmental effects covered in the empirical application



Annex C.
Economic and Environmental Outcomes Under Alternative Scenarios in the SAPIM Application

Annex Table C1. Baseline, Policy scenario 1, and Policy scenario 2: land allocation, input use intensity, production and farmers' profits

Crop	Land area, ha	Nitrogen use, kg/ha	Herbicide use, kg/ha	Production, kg/ha	Total production, kg	Profits, EUR/ha	Total profits, EUR
				Baseline			
RCG	2	33.7	-	4 609	9 219	221	443
Oats	4	72.4	0.82	3 112	12 449	226	903
Wheat	21	130.2	0.91	3 397	71 327	263	5 513
Rape	15	93.8	0.96	1 749	26 229	333	4 997
Total	42	-	-	-	119 224	-	11 856
				Policy scenario 1 – Removal of biofuel support			
Oats	27	74.5	0.84	3 302	89 167	240	6 473
Rape	15	89.2	0.94	1 728	25 914	298	4 468
Total	42	-	-	-	115 081	-	10 941
				Policy scenario 2 – New biofuel legislation EU and US			
RCG	4	39.6	-	4 913	19 651	236	944
Wheat	16	130.3	0.91	3 293	52 686	263	4 201
Rape	22	93.7	0.97	1 686	37 098	348	7 649
Total	42	-	-	-	109 435	-	12 794

In the Baseline, Reed Canary Grass (RCG) is cultivated in the 2 lowest productivity parcels with low nitrogen use intensity. The low nitrogen application rate is due to the high unit transportation costs and thus a low effective output price for RCG. However, support payments and low production costs make it profitable to cultivate RCG in the lowest productivity parcels. Oats cultivation takes place in the second lowest land productivities with low nitrogen and herbicide use intensities.

In comparison to the Baseline Policy scenario 1 shifts the land allocation towards oats and rape. Land allocated to RCG and wheat in the Baseline is now allocated to oats. Due to changes in price ratios and land allocation, the average nitrogen and herbicide application rate decreases for rape, while for oats both of these increases slightly, since oats cultivation shifts to higher land productivities. Relative to the Baseline, total profits slightly decrease.

The Policy scenario 2 makes RCG cultivation profitable and lowest productivity land is allocated to it. This policy scenario increases the profitability of wheat and rape cultivation, and thus these two crops exhaust the remaining land available for production. The fertilizer use intensity increases clearly for reed canary grass and slightly for wheat relative to the Baseline, whereas it slightly decreases for rape.

Annex Table C2. Baseline, Policy scenario 1, and Policy scenario 2: total nitrogen runoff, total phosphorus runoff, total herbicide runoff, total CO2-eq emissions and habitat index value

Crop	N-runoff, kg	P-runoff, kg	Herbicide runoff, kg	CO_2-eq emissions, tons	Habitat index value
			Baseline		
RCG	9	1	-	1	
Oats	24	5	0.04	11	
Wheat	192	27	0.22	70	
Rape	106	19	0.17	43	
Total	332	52	0.42	125	138.6
			Policy scenario 1 – Removal of biofuel support		
Oats	167	33	0.26	74	
Rape	103	19	0.16	42	
Total	270	52	0.42	116	135.7
			Policy scenario 2 – New EU and US biofuel legislation		
RCG	19	3	-	2	
Wheat	146	21	0.17	53	
Rape	156	28	0.24	63	
Total	321	52	0.41	118	158.1

Annex Table C2 presents total environmental effects under Baseline, Policy Scenario 1 and Policy Scenario 2. Relative to the Baseline the total nitrogen runoff decreases in Policy Scenario 1. This result is mainly driven by land allocation shift from fertilizer intensive wheat to the less fertilizer intensive crops oats and rape. Decreased input use intensity in Policy scenario 1 also results in a decrease of the total CO_2-eq emissions when compared to the Baseline. The habitat index value decreases in Policy scenario 1 relative to the Baseline, because of less diversified land use and no allocation of land to RCG which is almost twice as valuable habitat to butterflies than cereals.

In the Policy Scenario 2, higher application rates of fertilizer and herbicide inputs for wheat and rape is offset by increased allocation of land to RCG, which is cultivated with low fertilizer intensity and no herbicide use. Decrease in CO_2-eq emissions is mainly driven by an increase in the land allocated to RCG, which has low fertilizer intensity and thus low CO_2-eq emissions. Moreover, unlike other crops RCG sequesters carbon and thus its CO_2 emissions for soil are negative.

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