



**Accounting for biofuel
co-products in ILUC models:**

Where has all the protein gone?

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Summary

In the EU, most of the co-product distillers dried grains and solubles (DDGS) from cereal bioethanol plants is dried and used in formulated animal feed. It is shown that the protein content of the crops and other feeds displaced by wheat co-product DDGS should be equal to the protein content of wheat used to make the bioethanol.

The AGLINK-COSIMO model uses EU displacement data for a sensitivity case and this together with the E4tech model are the only ILUC models that properly take into account the protein content of biofuel co-products in the EU animal feed industry. These models also include increased yield due to increased demand, and both give net land use reductions for the production of bioethanol from EU wheat.

Some ILUC models take no account of biofuel co-products, while most models do not properly account for the protein content in the co-product DDGS from wheat bioethanol. In all these models, a large proportion of the protein in the wheat is unaccounted for in the model crop balance. This protein loss is not recognised nor discussed in the model reports.

The failure of other ILUC models to take proper account of the protein content of biofuel co-products, such as DDGS used as animal feed, will overestimate the land requirement for biofuels and substantially underestimate the co-product credit of the GHG emissions from ILUC for biofuels from cereals in the EU.

Introduction

When crops such as cereals and oilseeds are used for biofuel production, the starch or oil fraction is used for biofuels manufacture while all the remaining nutrients, including protein, are conserved and concentrated to provide high protein co-products, such as distillers dried grains and solubles (DDGS) and oil meals. These co-products are normally used for animal feed.

Animal feed dietary formulation targets are driven by economic considerations. In the US, a substantial quantity of corn ethanol co-products are used as liquid feed or as dried direct feeds in local feedlots. The significant logistics costs associated with moving (high) protein components from surplus regions to deficit ones means that the low cost of local protein sources relative to other components can justify the use of local DDGS as a cheap dietary energy source.

The animal feed industry in the EU operates differently from that in the US. In the EU, 73% of the protein in protein-rich animal feed is imported, primarily as soy meal from South America. Therefore in the EU, protein is a relatively expensive dietary component and so there is a strong economic incentive to use it efficiently in diets by accurately targeting optimum dietary protein levels. Most of the DDGS from bioethanol plants is therefore dried and used in formulated animal feed, where it partially displaces soy meal.

This displacement will reduce soy meal imports to the EU from S America and reduce the rate increase in soy bean growth in S America. The co-products from EU biofuel production therefore provide a substantial credit in land use and GHG emissions from land use change.

Animal feed formulation

In the EU, most of the DDGS from bioethanol plants is dried and used in formulated animal feed. Animal feed is formulated from up to 20 components to meet an optimum specification for each animal group. The specification includes required levels of about a dozen nutritive components including: metabolisable energy; digestible protein; minerals; vitamins; fats; and maximum levels of various anti-nutritive factors. Also for mono-gastric animals, the diet must include required digestible levels of essential amino acids (EAAs). The specification for protein concentration and energy content for a range of animal feed diets is shown in table 1.

Animal group	Crude Protein % of feed	Metabolisable	
		Energy MJ/kg	Net Energy MJ/kg
Calf -starter	18.0	11.3	
Dairy cattle 18 weeks	18.9	11.2	
Dairy cattle 31 weeks	31.0	11.4	
Beef cattle	14.0	10.8	
Pig - starter	23.0		10.8
Pig 30-65kg	18.8		9.8
Sow - lactating	17.9		9.8

Table 1 Source: Premier Nutrition

These specified animal feed protein concentrations are typically intermediate between the low protein contents of cereals (8% to 11%) and the high protein contents of DDGS and oil meals (27% to 48%). Therefore the required protein level for animal diet is achieved using a mixture of low protein cereals and high protein feeds. Wheat and soy meal are the variable low protein and high protein animal feed components in the EU animal feed industry, balanced by soy meal imports and changes to EU wheat production to meet EU wheat demand.

Nutritionists use a linear programming model to determine the least cost formulation to meet the feed specification for each animal diet depending on the available animal feed components and their price. The linear model includes nutritional component mass and energy balances such that the animal feed materials will meet the energy and protein requirements for the animal group feed specification. The costs of high protein animal feed i.e. imported soy meal in the EU are substantially higher than lower protein feeds such as wheat, so there is no case for using more protein rich feed than required to meet the protein and EEA requirements, since this will incur additional cost. The ratios by which particular co-products replace wheat and soy meal in different animal groups can be determined for each animal diet (Lywood 2009, ADAS 2010). The net displacement of other crops or feeds by biofuel protein co-products can be checked simply by using an overall protein balance.

Protein balance

During the biofuel production process, the protein in the cereals and oilseeds is conserved in biofuel co-products. With bioethanol production there is also an increase in total protein during the fermentation process, due to additional yeast protein generation from added nitrogen. This increase is typically equal to between 3% and 6% of the total cereal protein and an increase of 4% has been assumed.

Thus:

$$\begin{aligned} \text{protein in oil meal} &= \text{protein in oil seed} \\ \text{protein in DDGS} &= 1.04 \times \text{protein in cereal} \end{aligned} \quad (\text{eqn 1})$$

From the linear model used for animal feed formulation the nutritional component mass balance will balance the animal feed materials to meet the protein requirements for the animal group feed specification:

$$\frac{\text{protein in displaced crops or feeds}}{\text{protein in DDGS or oil meal}} = \frac{\text{digestible protein in DDGS or oil meal}}{\text{digestible protein in displaced crops or feeds}} \quad (\text{eqn 2})$$

The protein digestibility of different feeds depends on the animal types and on the other components in the DDGS, oil meal and displaced crops. For ruminants, the protein from all animal feeds is digested to fairly similar extents, so digestible protein is based on crude protein levels. For mono-gastric animals, higher levels of dietary fibre in DDGS and rape meal give lower protein digestibility than in lower fibre sources such as wheat and soy meal. Table 2 gives values of digestible protein for a range of animal feedstuffs for different animal groups. These assume that synthetic essential amino acids (EAAs), are added in the pigs and poultry feed formulation to avoid specific limiting EAA levels.

Animal Feed Data				
	Ruminants	Pigs	Poultry	Weighted Average
EU compound feed 2009				
mt/yr	38	50	49	
	Crude protein	Average AA digestibility	Average AA digestibility	Average digestibility
Raw material	(as fed)			
Wheat	11.0	88%	82%	89%
Maize	8.0	86%	86%	90%
Soy meal	48.0	89%	89%	92%
Rape meal	33.9	76%	78%	83%
Wheat DDGS	34.0	84%	84%	88%
Maize DDGS	27.0	76%	76%	83%

Table 2 Source: Premier Atlas 2008

As well as being the variable animal feed components in the EU animal feed industry, wheat and soy meal also have some of the highest protein digestibility figures. Therefore (from eqn 2), displacement of wheat and soy meal will give the lowest levels of protein displacement by biofuel co-product protein.

While a high proportion of DDGS is currently used in the EU for ruminant feed, this is likely to extend further into mono-gastric animals. It is therefore assumed that different animal feed raw materials will be fed to different animal groups in proportion to the EU compound animal feed usage. The average protein digestibility for each animal feed raw material is calculated in table 2. DDGS protein will displace more soy meal protein than wheat protein, so from table 2, the average value of:

$$\frac{\text{digestible protein in wheat DDGS}}{\text{digestible protein in displaced wheat and soy meal}} \quad \text{is equal to } 96\%.$$

Therefore for wheat bioethanol, from equations 1 and 2:

$$\frac{\text{protein in displaced crops and meals}}{\text{protein in bioethanol feed wheat}} = 1.04 \times 0.96 = 1.00$$

i.e. the protein content of the crops and meals e.g. soy meal displaced by wheat DDGS should be just about equal to the protein content of the wheat used to make the bioethanol.

If an ILUC model does not include elasticity of consumption, so that meat production and consumption stay the same, then the reduced protein production in feed crops displaced from animal feed by biofuel co-products should equal the increased protein production in additional feedstock cereals grown for biofuels production

If an ILUC model includes elasticity of consumption, there will be a small reduction in meat production and consumption as a result of the higher price of cereals (JRC 2010b). In this case, the ratio of:

$$\frac{\text{protein in displaced crops and meals reduced production}}{\text{protein in feed cereals production}}$$

as a result of biofuels production should be greater than 1.00

Accounting for co-products in ILUC models

The protein balance is calculated in different ways for different ILUC models depending on whether models provide data on animal feed substitution ratios, or changes in crops that are grown. Where data is not provided for protein content, the (as fed) protein content of feed wheat and DDGS are taken as 11% and 34% respectively (Premier 2008).

The data used for the protein balance in different ILUC models is detailed in appendix 1 and summarised table 3.

“DDGS displacement ratios” are amounts of animal feed displaced per unit of DDGS.

“Total replaced feed / wheat” is the total amount of animal feed displaced per net unit of wheat (and other cereals) used as a result of biofuel production.

“Wheat protein recovery” is the total amount of protein displaced per net unit of extra wheat protein.

Model	DDGS replacement ratios				Total replaced feed /wheat t/t	Wheat protein recovery t/t
	Soy meal /DDGS	Total oil meals /DDGS	Wheat /DDGS	Total cereal /DDGS		
	t/t	t/t	t/t	t/t		
IFPRI - IMPACT		0.00		0.00	0.00	0%
LEITAP				0.04	0.01	1%
GTAP		low		high	0.32	31%
IFPRI - MIRAGE		0.00		1.00	0.32	31%
CAPRI		Awaiting data				<51%
ESIM		Awaiting data				<51%
FAPRI - CARD	0.10	0.24		0.83	0.31	41%
Aglink-Cosimo base case		0.08		0.92	0.33	39%
Aglink-Cosimo sensitivity case		0.60		0.68	0.42	97%
E4tech	0.59		0.39		0	99%

Table 3 Sources: JRC 2010 a and b, IFPRI 2010, E4tech 2010,

The AGLINK-COSIMO model uses EU displacement data for a sensitivity case and this together with the E4tech model, are the only ILUC models that properly take into account the protein content of biofuel co-products in the EU animal feed industry. It is worth noting that the AGLINK-COSIMO model, including the sensitivity cases for EU co-product displacement and increased yield due to increased demand and the E4tech model both give net land use reductions for the production of bioethanol from cereals.

However, it may be seen that most ILUC models do not have a protein balance and the “wheat protein recovery” is substantially lower than 100%.

Where has all the protein gone?

Some models such as LEITAP and IMPACT, hardly account for co-products at all. Others models such as CARB and IFPRI-MIRAGE do not account for the higher protein content of DDGS compared to wheat, so simply substitute them for cereal on a weight basis (CARB) or energy basis (IFPRI). Other models such as ESIM and CAPRI use gluten feed instead of DDGS as the co-product of cereal bioethanol, so underestimate the available protein. The AGLINK-COSIMO work accepts that DDGS partially replaces oil meals, but uses substitution ratios from US practice for the base case. In all these models, a large proportion of the protein in the wheat is unaccounted for in the model crop balance. This protein loss is not recognised nor discussed in the model reports. Part of the reason for this is that some ILUC models that were originally written for US biofuels production have not been appropriately modified to reflect the EU animal feed situation.

The failure of most ILUC models to take proper account of the protein content of EU biofuel co-products, such as DDGS used as animal feed, will substantially underestimate the co-product credit of the DDGS and will therefore overestimate the net land requirement for biofuels and the GHG emissions from ILUC for biofuels from cereals in the EU.

Addition of synthetic essential amino acids

Mono-gastric animals such as pigs and poultry are not able to synthesise some amino acids and these must be obtained from the diet. These are called “essential” or “indispensable” amino acids (EAAs). Historically the utilisation of any protein feed in mono-gastric animals was limited by the limiting EAA in the formulation and excess protein could not be utilised and was excreted. The levels of EAAs in formulated animal feeds are therefore supplemented by addition of “synthetic” or “crystalline” EAAs such as lysine, threonine, methionine and tryptophan to boost protein quality and avoid the limitations of specific EAAs.

If protein is relatively cheap as in the US, excess protein can still be used to achieve individual EEA balances – however this is wasteful & causes additional GHG emissions from N excretions. When protein is relatively expensive as in the EU, it is economically preferable to achieve individual EEA targets using synthetic EAAs. Animal feed compounders in UK and Europe already add these EAAs in pig and poultry animal feed formulations to achieve specified animal diets.

The addition of EAAs is important to efficiently use DDGS as an animal feed for mono-gastric animals. DDGS protein has lower levels of some EAAs than soy meal, mainly due to lower levels of some EAAs in the wheat, but also due to some degradation of some amino acids (e.g. lysine) in the bioethanol conversion process.

However, with the introduction of synthetic EAAs, the limitations of DDGS protein are overcome by the increased addition of synthetic essential amino acids.

The large differences in the displacement ratios of soy meal by DDGS quoted in different references are primarily dependent on whether synthetic EAAs are used in the feed formulation. Examples of the ratios of soy meal displacement are shown below for pig feed formulation using corn DDGS in the US for cases with and without synthetic lysine addition.

Corn DDGS displacement ratios for swine/pigs							
	Source	Shurson 2003	Fabiosa 2009	Stein 2007	Baidoo 2008	Widmer 2008	Widmer 2008
Swine diet			Finisher	Most diets	Lactation	Grower	Finisher
Additional lysine		No	No	Yes	Yes	Yes	Yes
Soy meal crude protein				48%	47.5%	44%	44%
Corn replaced	t/t DDGS	0.89	0.94	0.57	0.38	0.44	0.46
Soy replaced	t/t DDGS	0.10	0.18	0.43	0.57	0.46	0.44

Table 4

It may be seen that where additional synthetic lysine has been included in feed formulations, the level of soy meal displacement by DDGS is substantially higher than when synthetic lysine is not added. For some diets at higher DDGS addition rates tryptophan or threonine become the limiting EAA using corn and wheat DDGS respectively and additional synthetic EAAs need to be added (Widmer 2008, Stein 2007).

Although the lysine level in DDGS is lower than in soy meal, the ratio of the methionine to crude protein is actually higher in DDGS than in soy meal and the fermentation processes substantially improves the phosphorus digestibility compared to wheat. Therefore, while displacement of wheat and soy meal by DDGS increases the rate of lysine and threonine addition, it reduces the rate of methionine and calcium phosphate addition.

Since the cost of high protein feeds e.g. soy meal in the EU is substantially higher than low protein feeds e.g. maize, then synthetic EAAs will be routinely used in formulated mono-gastric animal feeds to maximise the protein utilisation in wheat and DDGS. No mention is made in any of the ILUC model reports on whether the DDGS displacement of other crops or feeds takes into account the use of synthetic EAAs.

Protein content variability of DDGS

It has been proposed for example (Fabiosa 2009), that high variability of the protein content in DDGS will lead to lower utilisation of DDGS protein content.

DDGS is produced from a range of processes, including breweries, distilleries as well as industrial bioethanol plants. In the brewing and distilling industry, there is a wide range of technology and since DDGS is produced at low rates and is of low value compared to potable alcohol, less effort is made to ensure consistency. There is therefore a large variability in the products from these plants. Data showing the range of variability of DDGS and the reasons for this range in the US is given by Shurson (2003).

However, the scale of DDGS production from industrial bioethanol plants is much greater than that from brewing and distilling. For example the DDGS output from a

single large scale cereal bioethanol plant is 1.8 times that of all the DDGS from the brewing and distilling industry that is used for animal feed in Great Britain. The sales of DDGS from modern industrial bioethanol plants are therefore sold to animal feed compounders with specific quality guarantees, as a differentiated product from DDGS from breweries and distillers: some biofuel producers brand their DDGS. Therefore the variability of DDGS quality between plants is not relevant to the formulation of animal feeds using DDGS from modern industrial bioethanol plants.

There is variability from batch to batch in the protein content of all animal feeds. For grain crops this is due to factors such as grain variety, soil conditions, fertiliser use, weather, and harvesting. For processed feeds such as oil meals and DDGS, there is also variability due to processing changes. The variability will also depend on the degree of mixing of feed from different sources, before it is used as animal feed.

For industrial cereal processing plants, cereal is delivered from a variety of farms on any day and loaded into plant storage. However, there is little mixing between these sources of grain in storage, so there is still significant variability in the cereal that is delivered from storage for processing. Daily measurements of wheat protein content into processing on a large scale industrial bioethanol plant over three months are shown in table 5.

Feed wheat protein daily data over 3 months	
Average protein (as fed)	11.2%
Standard deviation	0.44%
Coefficient of variation	3.91%

Table 5 Ensus data

Wheat used for industrial bioethanol production is similar to that used for animal feed. The variability in the protein content of supply from wheat storage will therefore be similar, whether the wheat is used for animal feed formulation or for bioethanol production.

In a bioethanol plant a large quantity of cereal is processed in the fermentation process at any one time, during which it is very well mixed. In a modern large scale ethanol plant any fermentation batch will originate from about 50 lorries of cereal delivered to the plant from a range of farms. Due to the mixing of this number of wheat sources, the variation of the protein content of the DDGS due to the variation of wheat protein content will be minimal. Variations in the protein content of the DDGS will therefore depend primarily on variations over time of the plant ethanol yield.

Daily plant measurements of DDGS protein content from a large scale industrial bioethanol plant over three months are shown in table 6.

Wheat DDGS protein daily data over 3 months	
Average protein (as fed)	33.6%
Standard deviation	1.09%
Coefficient of variation	3.25%

Table 6 Ensus data

The variation in protein content (as a percentage of average protein content) of DDGS is compared shown in table 8 with other primary feed components.

Coefficients of variation of protein	
Wheat	3.91%
Soy meal	2.30%
DDGS	3.25%

Table 7 Source: Ensus, Shurston 2003

It may be seen that the variation in protein content (as a percentage of average protein content) is lower for DDGS than for feed wheat.

There is a variation from year to year in the protein content of feed wheat, which will feed forward into the DDGS. However, this will be taken into account in animal feed formulations.

Farmers and formulators like to avoid having too high a percentage of any major nutrient coming from a single raw material in feed formulations, since any major variation in the high percentage raw material gives variations in the formulated animal feed. In some cases with current EU animal feeds, 80% of the amino acids are from soy meal and this gives a risk of variation in the amino acids content of the feed. DDGS as an additional animal feed material displaces a proportion of the soy meal content of the ration. Since the variation of the DDGS amino acid content will be independent of the variations in other feed components it will provide a further reduction in the overall variability of the formulated animal feed protein.

If animal feed compounders add excess soy meal to an animal feed formulation to guarantee a given protein level in the animal feed, taking into account the variability in the protein content of each component, the increased addition of DDGS will reduce the amount of excess soy meal that needs to be added.

References

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Appendix – Model details

Aglink-Cosimo (JRC 2010a)

The report accepts (P 52) that “it is likely that in the EU, where animal diets and the structure of feed markets are different, and given the significant vegetable protein deficit, protein-rich wheat DDG replaces a higher proportion of protein in animal diets”. However, “The baseline assumptions regarding the use of DDG as animal feed in the EU are mainly based on observations in the USA. data from as the base case for EU wheat bioethanol” (P52). The data from the US Dept of Agriculture assumes (P26) that on average DDGS displaces 0.92 t/t coarse grains and 0.08 t/t of oil meals. Oilseeds are not disaggregated (P101) in the Aglink-Cosimo model. It is not stated what protein content is assumed for oil meals and a protein content of 40% has been assumed in table 3 of this note.

A sensitivity case is done for a EU case where DDGS displaces 0.68 t/t coarse grains and 0.60 t/t of oil meals. This gives a significant reduction in EU oilseed imports and a reduction in world land use compared to the baseline of 410,000 ha. Taken together with the case of faster yield growth, the 2020 EU renewable transport fuels target would be achieved with a net reduction in world land use.

ESIM and CAPRI (JRC 2010a)

It is stated (P 100) that “corn gluten feed is not a biofuel by-product: it is a by-product of the high fructose corn syrup industry and does not depend on ethanol production. Therefore we ignore it in this report”. However, ESIM and CAPRI models both assume that corn gluten feed is the co-product of bioethanol production from cereals: ESIM (P62) “The production of gluten feed is defined as the sum the different cereals used in biofuel processing each multiplied by its respective technical extraction factor” and CAPRI (P 80) “wheat used in ethanol production implies production of gluten feed”.

Corn gluten feed only has an as fed protein content of 20% and ESIM assumes (P62) an extraction rate of 0.285 t/t wheat. This compares to a DDGS as fed protein content of 34% with an extraction rate of 0.33 t/t wheat for a modern wheat ethanol plant. Therefore the maximum protein utilisation will be reduced to 51%, before any consideration of the substitution ratios between DDGS and replacement animal feeds.

IFPRI (IFPRI 2010)

It is stated (P22) that “The GTAP-E model (like that used in this study) does not take account of the potential impact of biofuel by-products which the authors acknowledge to be an important limitation”. As a result of this “Co-products of the biofuel industry such as DDGS,are used as substitutes for feedgrains in livestock production” based on energy content. Since the as-fed metabolisable energy content of wheat DDGS is similar to that of wheat, IFPRI assumes that DDGS will replace wheat on approximately a wt/wt basis. This effectively means that the higher protein content of DDGS is not taken into account and only about 31.5% of the DDGS protein is accounted for.

LEITAP (JRC 2010b)

LEITAP models DDGS as replacing only 1.5% by weight of the wheat used to produce the bioethanol (Table 28). It is stated (P63) that “like all substitutions between inputs in the GTAP structure, animal feed substitutions are done on the basis of relative price, rather than balancing of protein and energy contents. It was assumed that in the 2001 database the value of by-products equals15% of the value of wheat in ethanol (also called DDGS). Since LEITAP does not balance protein and energy contents, it has been assumed for Table 3 of this note that LEITAP models DDGS as displacing cereal crops.

IMPACT (JRC 2010b)

As is stated (P91) “IMPACT does not attempt to include by-products.” Therefore neither the protein nor the energy of the biofuel co-products are accounted for.

GTAP (JRC 2010b)

The basis of GTAP co-product substitution is not provided in the report. However, the model estimates (P32) that there will be 30% recovery of net cropland for EU wheat ethanol from the consideration of by-products.

It is stated in the GTAP work for CARB (Tyner 2010) for the GTAP – BIO model, that “Following the literature, they used values of 25, 30, and 20 for the elasticities of substitution between coarse grains and DDGS in the dairy farms, other ruminant, and non-ruminant feed structure, respectively and a small value of 0.3, for the elasticity of substitution between the energy and protein feedstuffs because DDGS could displace a portion of meals in some feed rations”.

The outcome of using these elasticities is not entirely clear, but the 30% land recovery and lack of protein and energy balances suggests that GTAP models DDDS as primarily displacing cereals.

FAPRI (JRC 2010b)

DDGS displaces a mixture of grains and oilmeals, with displacement for grains allocated to corn, wheat, barley, sorghum, oats and displacement for oil meal is allocated to soy, rape, and sunflower meals. The displacement ratios are not provided, so the protein balance has been determined using a co-product recovery of 31% (table 7) and using crop by crop FAPRI model data (table 54).