Co-product Allocation in Life Cycle Assessment: A Case Study

Extended Abstract 2009-645-AWMA

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INTRODUCTION

As the interest toward industrial sustainable practice grows; companies are increasingly turning to life cycle assessments (LCA) as a metric to measure sustainability impacts by analyzing the environmental and energy burden of their products and services. LCA is a method of measuring these impacts through the raw material procurement, production, usage and disposal stages of a products life cycle.[1] LCA for example can be used to measure a products carbon foot print or determine the viability of alternative fuels. The outcome of LCA's can vary greatly depending on the assumptions made in the assessment; specifically for processes which produce multiple products. Allocation is a method of distributing the production energy consumption and environmental impacts between products and co-products through the determination of a co-product credit. This credit is utilized in and can have a significant impact on the overall LCA result.

LCA standards call for avoiding allocation when possible by including within the boundary of the assessment production processes for materials that are replaced by co-products.[2] A common approach in LCA and net energy analysis, known as the "system expansion" method (also know as the "substitution", "displacement", or "replacement" allocation method), credits input energy to co-products associated with the products displaced in the market. This method uses the life cycle energy required to produce the material that is displaced by the co-product, attributing this energy to the co-product in subsequent stages of an energy and environmental analysis.[3] The U.S. EPA has stated that the displacement method is the preferred allocation method for life-cycle energy and GHG analyses in its analysis of the Renewable Fuel Standard Program.[4]

CASE STUDY

To demonstrate the importance of allocation assumptions in overall life cycle assessment studies, we have performed a co-product allocation assessment for the green house gas (GHG) emissions from corn grain ethanol. We have used the displacement method of allocation, to allocate the GHG emissions between ethanol and its co-product, distillers grains (DG).[a] DG are a co-product produced during dry grind ethanol production and currently are used primarily in cattle feed rations. Ethanol co-product credit estimates are typically determined by using a fixed cattle feed

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[a] There is a wide variety of forms that DG can take. For the purposes of this paper we have assumed that the ethanol co-product is dried distillers grains with solubles.

component displacement ratio and DG inclusion rate. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model uses the displacement method and assumes that DG displaces a constant ratio of cattle feed.[5] The ERG Biofuels Analysis Meta-Model (EBAMM) also assumes a constant feed displacement ratio.[6] The cattle feed displacement ratio is the amount of cattle feed that is displaced per pound of DG fed, based on the relative nutritional values of the feeds. The DG inclusion rate is the percentage of DG included in cattle diets. Since farmers tend, in practice, to feed varying rates of DG. In our co-product estimate, we have varied the inclusion rate to determine the effect on the co-product credit. The energy and protein value of DG to cattle both decrease as inclusion rates increase,[7] thus, the typical method of using a constant replacement ratio is not an appropriate assumption in estimating the quantity of feed displaced.

Using the displacement method, the ethanol GHG co-product credit (i.e. the GHG emissions attributed to DG production) is determined by assigning to the DG, the emissions from the animal feed it displaces. DG provides energy and protein in cattle diets which displaces corn grain and protein supplements usually found in cattle rations. We have determined both an energy and protein portion of the co-product credit, assuming corn and urea are displaced in the cattle diet.[b] We have then determined the overall GHG co-product credit and used this to determine the life cycle GHG emissions of ethanol based on a representative ethanol plant. The EBAMM model has been used for baseline life cycle GHG emission data.

Experimental Methods

The protein and energy credits are determined by estimating the amount of protein and energy displaced in cattle diets by feeding DG and then multiplying these values by the life-cycle GHG emissions of the displaced feed component.

The amount of DG fed to cattle commonly varies from 15% - 40% of the total feed dry matter intake (DMI). The percentage added to the feed ration depends upon its purpose — whether serving as an energy or protein source. Inclusion of DG in cattle diets at levels below 15% has the primary purpose of providing protein. At higher levels, after protein demands have been met, DG serve as an energy source and excess protein is excreted by the animal.[8] The animal's health and beef quality are not significantly affected when cattle are fed distillers grains up to 40% of their DMI.[9] At DG inclusion rates above 15%, excess protein is consumed but cannot be utilized by the animal, so passes through and is eliminated. This excess protein should not be included in the co-product credit because it is not displacing other protein supplements in the cattle diet.

Corn credit

The feeding value of DG decreases as it is included at higher rates in cattle diets (Table 1)

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[b] Note that it would also be appropriate to consider the displacement of other common protein supplements such as soybean meal. In the attempt to simplify the example only urea has been considered here.

Table 1. Energy feeding value of distillers grains by DG inclusion rate[c]

	15%	20%	25%	30%	35%	40%
Corn Replaced (kg corn replaced/kg DG fed)	1.37	1.23	1.14	1.07	1.02	1.00

Equation 1 illustrates the method for calculating the corn portion of the coproduct credit.

$$\text{CornCredit} = \frac{\text{DG Production}(\text{kg}_{\text{DG}}/\text{kg}_{\text{corn}})}{\text{EtOH Yield}(\text{L}/\text{kg}_{\text{corn}})} * \text{DG Feeding Value}(\text{kg}_{\text{Corn}}/\text{kg}_{\text{DG}}) * \text{Corn Production GHG Emissions}(\text{kg}/\text{kg}_{\text{corn}}) \qquad \textbf{(Eq. 1)}$$

Urea Credit

Inclusion rates of urea were estimated using the Beef Ration and Nutrition Decisions Software (BRaNDS) model developed by the Iowa Beef Center using National Research Council feeding recommendations.[10] The diet was balanced for appropriate energy and protein levels using corn, urea and forage. Because protein requirements in cattle rations change with cattle weight, two diets were developed for finishing cattle - one for cattle weights of 341kg - 455kg and another for cattle weights of 455kg - 614kg. The overall inclusion rates of urea in beef diets were then taken to be the average of the diets for these two weight classes. The total amount of urea displaced relative to ethanol production was calculated based on ethanol production, the associated DG production rate, the amount of DG included in cattle diets, and the amount of urea traditionally fed in the cattle diet (equation 2). The average urea inclusion rate was estimated to be 0.9% of the dry matter intake. The amount of urea displaced in cattle diets at DG inclusion rates of 15%, 20%, 25%, 30%, 35% and 40% of cattle dry matter intake was multiplied by the life-cycle GHG emissions of the displaced urea to determine the urea protein of the energy credit (equation 3).

$$\text{Urea Displaced (kg/L}_{\text{EtOH}}) = \frac{\text{DG Production (kg/bucorn)}}{\text{DG Fed (kg/hd/day)}} * \frac{\text{Urea Fed (kg/hd/day)}}{\text{EtOH Production (L/bucorn)}} \qquad \textbf{(Eq. 2)}$$

$$\text{Urea Credit (MJ/L}_{\text{EtOH}}) = \text{Urea Displaced}(\text{kg/L}_{\text{EtOH}}) * \text{Urea Production Energy (MJ/kg)} \qquad \textbf{(Eq. 3)}$$

Total Co-product Credit

The corn and urea portions of the co-product credit are then summed to determine the overall co-product credit. This co-product credit can then be used to determine the life cycle GHG emissions from ethanol production. We have used the life cycle GHG input emission values from a representative ethanol plant[11] as shown in equation 4 and varied the co-product credit based on our analysis.

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[c] These values are for dried distillers grains with solubles, one of the more prominent types. The values derived from data in Klopfenstien et al using a quadratic interpolation for DDGS ($R^2 = 0.9992$).

Life Cycle CO_{2e} Emissions = (Ag Phase + Ethanol Plant – Co-product Credit)/NHV_{EtOH} + Dist Stage

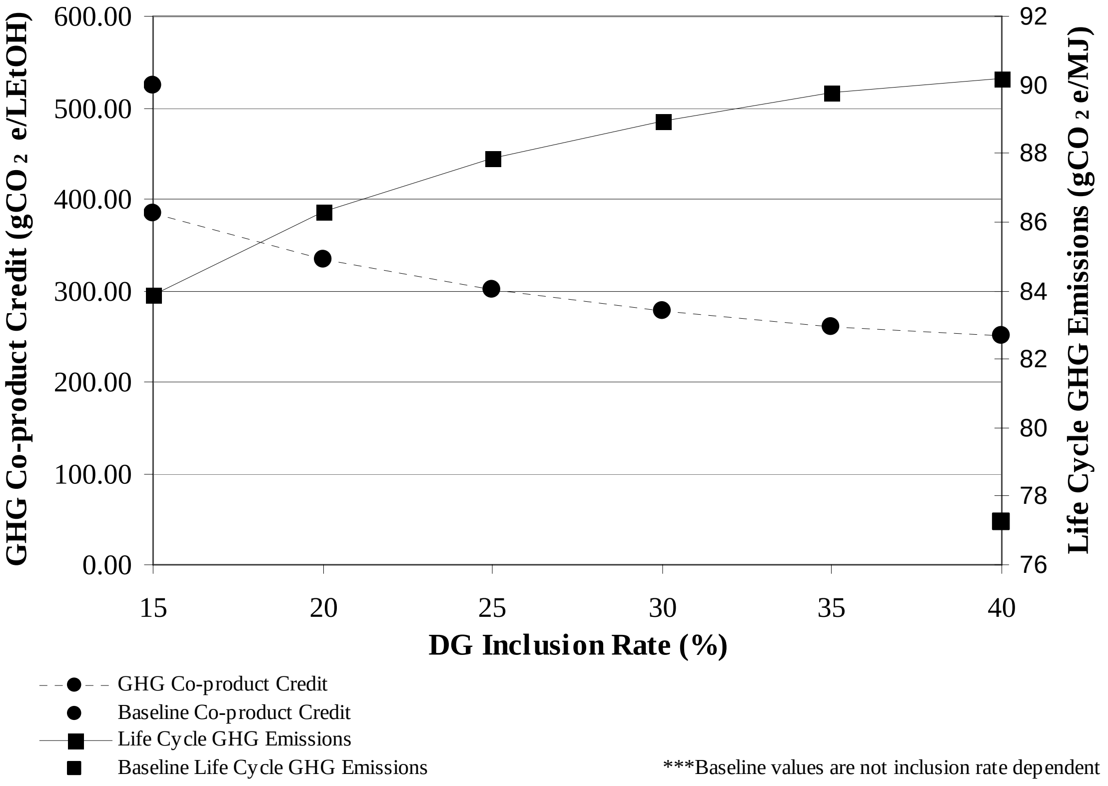
(Eq. 4)

Life Cycle CO_{2e} Emissions = (780.5g CO_2e/L+1353.9g CO_2e/L-**Co-product Credit**)/(21.2MJ/L) + 1.4g CO_2e/MJ

Results and Discussion

As the inclusion rate of DG increases, the overall feeding value of the grain decreases and results in a decreasing co-product credit and increasing level of life cycle GHG emissions. Figure 1 shows the estimated ethanol co-product credits and life cycle ethanol GHG emissions varying with DG inclusion rates. The baseline cases for each are also shown. The baseline cases do not vary with inclusion rate and assume a constant feed displacement ratio and feeding value.

Figure 1. Ethanol GHG Co-product Credit and Life Cycle Emissions



Comparing the life cycle ethanol GHG emissions to gasoline can be helpful in determining the relative impact of ethanol production. Table 2 illustrates the overall GHG emissions displaced from ethanol as opposed to gasoline for the baseline case[11] (which includes a constant DG feeding value and displacement ratio) and for each of the DG displacement ratios.

Table 2. GHG emissions displaced by ethanol by inclusion rate

	Base line	15%	20%	25%	30%	35%	40%
GHG displaced by ethanol (kg CO_2e/L EtOH)	-0.18	-0.11	-0.08	-0.07	-0.05	-0.04	-0.04

Taking into account the variable DG inclusion rate, the GHG emissions displaced by ethanol is as much as 77% lower than the base line ethanol displacement rate.

SUMMARY

LCA is a helpful tool for measuring the energy and environmental impacts of a product. Allocation plays an important role in LCA. Assumptions made during allocation can have a significant impact on the overall LCA result. In the illustration developed here it was shown that GHG co-product credits for ethanol and subsequently the overall life cycle GHG emissions, depend on assumptions made regarding the end use of the co-products. The method presented in this paper can likely be adapted to determine co-product credits associated with both feed and fertilizer co-products from the ever increasing number and types of biorefinery co-products. Co-product credits for these applications may vary with the level of co-product used for a specific application. In the case of animal feed the value of the co-product most likely depends on the amount fed and in the case of fertilizer the value to the soil most likely depends on the amount applied. The case study presented in this paper demonstrates that assumptions are an important aspect and play a significant role in the overall results of LCA.

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KEYWORDS: LCA, GHG emissions, ethanol, co-product allocation