A Quantitative Assessment of the Determinants of the Net Energy Value of Biofuels♣

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Abstract: Many studies have investigated the net energy balance of biofuel products (in terms of savings on fossil fuels) and assessed reductions in greenhouse gas emissions from substituting biofuels for fossil fuel. These studies provide very different results, with net balance ranging from highly positive to negative. Our study analyzes a large sample of these studies by retrieving the main parameters used and converting them into units of measurement that are comparable. This information is used to unravel the main determinants of the differences in net energy value across studies. Our approach relies on descriptive statistics and econometric estimates based on a meta-analysis methodology. Our results suggest that the large variability across studies can be explained by the degree to which particular inputs (i.e. nitrogen, farm labor) are controlled for, and the way that fossil energy consumption is allocated to the various co-products.

Keywords: biofuels, net energy value, meta-analysis.

♣ We thank the two anonymous referees, Vincent Réquillart and participants at GTAP 2009 for helpful suggestions. Financial support received by the "AgFoodTrade - New Issues in Agricultural, Food and Bioenergy Trade" (Grant Agreement no. 212036) research project, funded by the European Commission, is gratefully acknowledged. The views expressed in this paper are the sole responsibility of the authors and do not necessarily reflect those of the Commission.

1. Introduction

Biofuel production, in both developed and developing countries, has been increasing since the early 2000s. A significant proportion of United States (US) corn production (more than a third), European Union (EU) rapeseed production (more than half) and Brazilian sugar cane production (almost half) is being channeled into the energy market. The rapid and continuing growth in US bioethanol and EU biodiesel production is due mainly to public policies. The EU and the US support the development of biofuels through subsidies, tax exemptions or mandatory blending in gasoline or diesel. Taking account of the subsidies at the Community/federal level and member state/state levels, Steenblik (2007) finds that support for biofuel production reached USD 4.5 billion in the EU and USD 6 billion in the US in 2006.[1]

Public authorities justify and legitimize support for biofuel production based on several motives. One of the main ones is encouragement for the production of renewables to substitute for conventional fossil fuels in an attempt to mitigate climate change and reduce dependency on energy imports. Other motives include providing an outlet for agricultural production to support farm incomes or/and help in the reform of agricultural policies. Recently, the environmental balance involved in biofuel production and use has been questioned in several OECD countries, and resulted in a dilution of the initial support. Some potentially negative effects of biofuels, e.g. competition over land and water with food production, have led several developing countries to re-examine their objectives (Global Bioenergy Partnership, 2009; Searchinger, 2009).

It is becoming vital to assess whether the non-market benefits related to biofuel are large enough to compensate for its negative externalities, such as use of land, fertilizers and water

[1] Preliminary estimates for 2008 suggest that these figures will be much higher, see www.globalsubsidies.org. Brazilian ethanol production is currently driven more by market prices than by subsidies, but initially was largely government driven; there is still some mandatory blending with gasoline.

for non-food production, and the cost to taxpayers and consumers. Reductions in Greenhouse Gas (GHG) emissions are the most important issue regarding the potential benefits of biofuels. Other non-market benefits are likely to play a more limited role in an overall cost-benefit analysis.[2] A large body of work that relies on Life Cycle Analyses (LCAs) to investigate biofuel production, provides very different, sometimes contradictory results for key issues such as net energy value and net GHG balance (Menichetti and Otto, 2009). The wide variability in these results makes it difficult to come to any firm conclusions.

Although a focus on the benefits in terms of reductions in GHG emissions would seem useful, some recent findings have introduced controversy into how emissions savings are measured. It seems that it is necessary for some major scientific uncertainties to be resolved. First, it is possible that current methodologies underestimate quite dramatically the net nitrous oxide (N_2O) emissions from agricultural production (Crutzen et al., 2007). Because of the high global warming power of this GHG (300 times more than carbon dioxide - CO_2), concerns have been raised about the impact on GHG of energy crop production. Also attention has been drawn to the indirect consequences in terms of GHG of global changes in land use (Searchinger et al., 2008). A major expansion in biofuel production would lead to further carbon releases from forest and pastures being converted into land for agricultural production. Changes to land use result in increased non-CO_2 gas releases, in proportions that are controversial, and with effects that are not yet understood. Some of these effects are indirect (e.g. US use of corn for ethanol competes for land with other crops, results in lower US soybean production and indirectly increases purchase of soybean by the EU from Latin America, with consequences on land use in Argentina or Brazil). Hence, LCA would need to be supplemented by a detailed economic model and data on land use and agro-ecological

[2] For example, even in the most optimistic scenarios, local biofuel production would only slightly dent EU and US oil imports, and dependence from foreign sources would remain high. Other positive externalities, such as increasing rural employment, are not believed to affect considerably the outcome of a cost benefit analysis (European Commission, 2006).

conditions to capture indirect changes in GHG emissions (Fargione et al., 2008). Finally, the GHG balance is likely to vary with the quantities of biofuels produced, and these variations will be non-linear due to the need to mobilize factors whose marginal productivity is often decreasing. That is, the validity of LCAs beyond marginal increases in biofuel production appears limited.

All these additional factors suggest that assessing the impact of biofuels in terms of GHG emission reductions requires consideration of the changes in prices in interrelated markets, relationship between global land use and prices, impact on livestock and feeding methods, estimates of carbon dioxide (CO_2) and methane (CH_4) releases, and a reassessment of the nitrogen cycle in soil, water and the atmosphere (Howarth et al., 2009). Such a global GHG assessment seems beyond current scientific capacity.

In this study, we do not attempt to assess the GHG balance; rather we focus on the energy balance of biofuels, i.e. the degree to which consumption of fossil fuel is reduced when gasoline and diesel are replaced by biofuel. This is an important building block in the CO_2 balance. It is less controversial than a complete GHG balance assessment, subject to in terms of the considerable uncertainties

Even on the seemingly more straightforward issue of energy balance, results vary widely across studies. In a path-breaking study, Farrell et al. (2006) scrutinize the hypotheses underlying a group of studies on corn ethanol, and carry out a harmonization exercise by replacing the "odd" values found in some studies with the seemingly more suitable values found in others. Their objective was to estimate a reliable value for the net energy of corn ethanol. Although we build on Farrell et al.'s methodology, we do this from a different standpoint. Rather than trying to harmonize the results of these studies and reducing their variability, we aim to uncover the main determinants of this variability. Our objective is to unravel how the results are affected by the choice of a particular method for controlling the energy content in inputs, estimate indirect energy consumption through capital or labor, or allocate energy consumption across co-products. Different authors have made particular assumptions, which at first sight appear harmless, but which may have a significant effect on the results obtained.

2. Methodology

The various studies published in journal articles, reports and working papers, on biofuels, range from finding a very positive balance to a negative balance. That is, in the latter case, the production of biofuel uses more energy than what its combustion can actually yield (calorific power or heating value). Careful examination of these results suggests that this variability would emerge irrespective of feedstock, type of biofuel and country of study.

In order to unravel the determinants of this disturbing variation in the estimations of the energy efficiency of biofuels, we carry out descriptive statistical and meta-analysis of these studies. This requires an objective sampling procedure of the studies to ensure that there is no selection bias. To construct our sample, we implemented a two-step selection protocol. First, we sent a questionnaire to eight of the researchers working on LCA and biofuel impact assessment in public universities and research centers, to ask which bibliographic databases and keywords they used in their work. The responses showed that there was little variation in these, which suggests that including more scientists would make only marginal differences. We carried out searches on these data sources using the keywords indicated, in both English and French.[3] We checked the references mentioned in the selected studies to expand our set of studies. This exercise produced 118 studies assessing the energy efficiency of one or several types of biofuel. We indexed these studies using bibliographic software (JabRef®) in order to

[3] The quoted sources were Web of Science, CAB Abstracts, Econlit and the electronic catalogue of Blackwell and Elsevier, as well as Google Scholar (some of them also indicated the use of regular Google). The used keywords were "ethanol", "biodiesel", "energy value", "biofuel" in various pairs and combinations. Note that the search indicated studies that were not available on the internet or in published journals. In such cases, authors were approached. A few of them sent the whole study, paper version.

make it easier to access the main text and tables. The content of these studies was examined and information on the different steps in the life cycle analysis (i.e. amounts of input per hectare, yields, co-products, coefficients) was retrieved and collected in a spreadsheet. We conducted a careful treatment of this information to ensure that all data were in comparable units. Finally, we collected and encoded qualitative information from these studies.

Not all of the studies were suitable for our purpose and some were eliminated. Some were based on non-original data (5 cases); others duplicated results published in other papers, or at least relied on the same figures in relation to the LCA. Sixteen studies provided conclusions although no LCA was carried out, or at least no results were provided. In some, the methodology was described badly and was not clear about which inputs were taken into account (17 cases). We also eliminated studies that completely ignored the energy costs either of the agricultural production phase or the processing phase (13 cases). Finally, some studies presented only aggregate results or not sufficient detail to compute net energy balance in a way that was comparable with the results of the other studies. We were left with 59 observations which we use for our analysis.[4] The list of studies used in our analysis is presented in the appendix. It is possible that the selection process generated a bias: for example, studies with "sloppy" reporting of LCA results may also have taken shortcuts that would bias net energy results. However, we believe that most of the sampling bias has been eliminated and that our data are sufficiently harmonized to enable comparison.

The statistical analysis also requires that the various coefficients and explanatory variables and the main variable of interest are in comparable units. Here our focus is on Net Energy Value or NEV. Let E_{input} be the total energy expended to produce 1 liter of biofuel, E_{output} the energy contained in 1 liter of biofuel and $E_{coproduct}$ the energy credit attributed to co-products.

[4] Note that we distinguish between "observations" and studies, since some studies provide results for several feedstocks, each of which is an observation in our sample. In the meta-analysis, two outliers in our list of usable studies were excluded by the Hadi test, i.e. one from European Commission (1994) and one from Pimentel and Patzek (2005).

NEV, i.e. E_{output}-(E_{input}-$E_{coproduct}$) is a simple measure that is easy to manage.[5] Where this measure was not in joules per liter, we constructed it from the results. The final sample includes 54 variables. These explanatory variables, which are potential determinants of the various net energy values in different studies, include type of feedstock, inputs to feedstock production, transportation and processing, their energy content (including capital and labor), country, year, energy source (e.g. coal, electricity, biomass such as bagasse), and allocation of the various co-products. The database was then treated using the Stata® software.

The studies in our working sample cover production of biodiesel and ethanol, based on several types of feedstock. The number of usable studies in our sample differs widely depending on type of feedstocks. So does the robustness of crop specific results. For example, comprehensive information on NEV and explanatory variables is available for 30 studies that examine production of corn based ethanol, while only two comprehensive LCAs deal with sunflower based biodiesel, which introduces the issue of possible individual outliers and their effects. For this reason, where we need to control for intrinsic variability in the sample, some of the analyses focus on the corn subsample.[6]

3. Results and the sources of heterogeneity

Our examination of the sample studies suggests wide variability in NEV and some of the explanatory variables. In particular, the extent to which fossil energy is accounted for in the production and transportation of inputs and outputs, the values of parameters such as yields from the farm and processing sectors, and how co-products are accounted for, vary greatly.

The NEV of biofuels based on different feedstocks. Figure 1 depicts the median NEV and dispersion for biodiesel or ethanol derived from different crops. We can see that median

[5] Because some studies directly deduct the energy from some co-products from the input (i.e. bagasse in sugar cane) and other count separate credit for it, using a net energy ratio rather than a difference would be less straightforward.
[6] For example, nitrogen application rates will differ for corn and soybeans since the latter is a legume which can fix atmospheric nitrogen through interaction with nodulating bacteria.

energy value per liter is slightly higher for biodiesel from rapeseed than for ethanol from sugar cane, even without correcting for the different calorific power of biodiesel and ethanol (NEV is expressed in terms of net energy, i.e. joules, per liter of biofuel, while the energy content of a liter of biofuel differs between ethanol and biodiesel). This finding contrasts with what is generally assumed. One explanation for it may be that the sample of studies on sugar cane includes some rather old studies and several cases based on US cane, while Brazilian cane ethanol is poorly represented in the sample – possible because the Brazilian studies are in Portuguese and were not identified by our sampling procedure. Some of the studies on Brazil are also rather old and may refer to a technology that has now improved. Figure 1 also shows that two studies on rapeseed (European Commission, 1994; Janulis, 2003), which provide results of a very high net energy balance, are driving average results. Although a core principle of this type of analysis is not to remove outliers, it is notable that the net energy value derived from other studies, on average, is similar to that for cane based ethanol.

Another interesting result is the very large variability in the results for biodiesel from rapeseed and ethanol from corn, compared to those for sugar cane ethanol, despite the sample including studies on Brazil and US states in the latter case (Figure 1). It may be that the production process is more standardized or is simpler in terms of inputs to the agricultural and processing phases. Median NEV for other crops is based on samples that are too small to allow useful interpretation. Overall, net energy value is lower for cereal based than sugar cane ethanol.

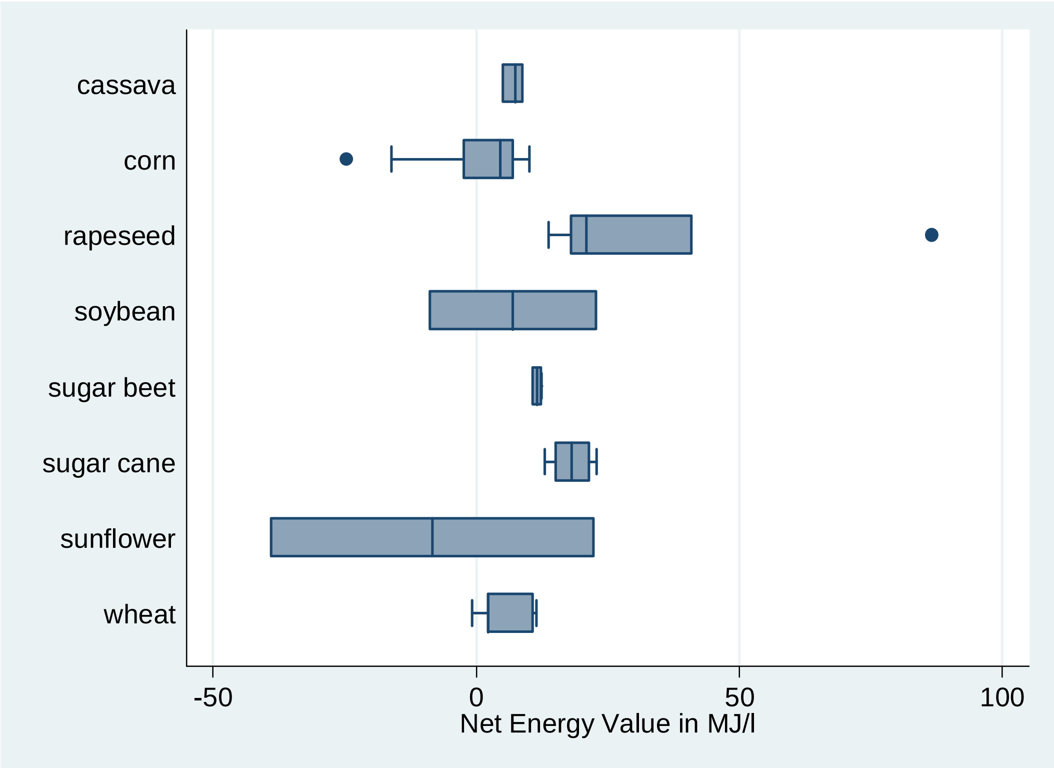

Figure 1: Median Net Energy Value and Dispersion by Feedstock

The issue of co-products. A classic problem with joint production is that there is neither a theoretically consistent nor satisfactory way of allocating inputs unless the technology displays particular and rare forms of separability (Blackorby et al., 1978). Our sample of studies uses different methods and makes different assumptions to allocate the fossil energy consumed by different co-products. Figure 2 shows the variability in the results for the different co-products. For rapeseed and soybean based biodiesel and, despite the small sample, wheat based ethanol, the assumptions made about co-products seem to be more important drivers of the results than in the case of sugar cane or even corn based ethanol. The valuation of co-products (which include oilcake used for feedstuffs and some co-products from the processing phase such as glycerin) has a large influence on the NEV of rapeseed and soybean based biodiesel.

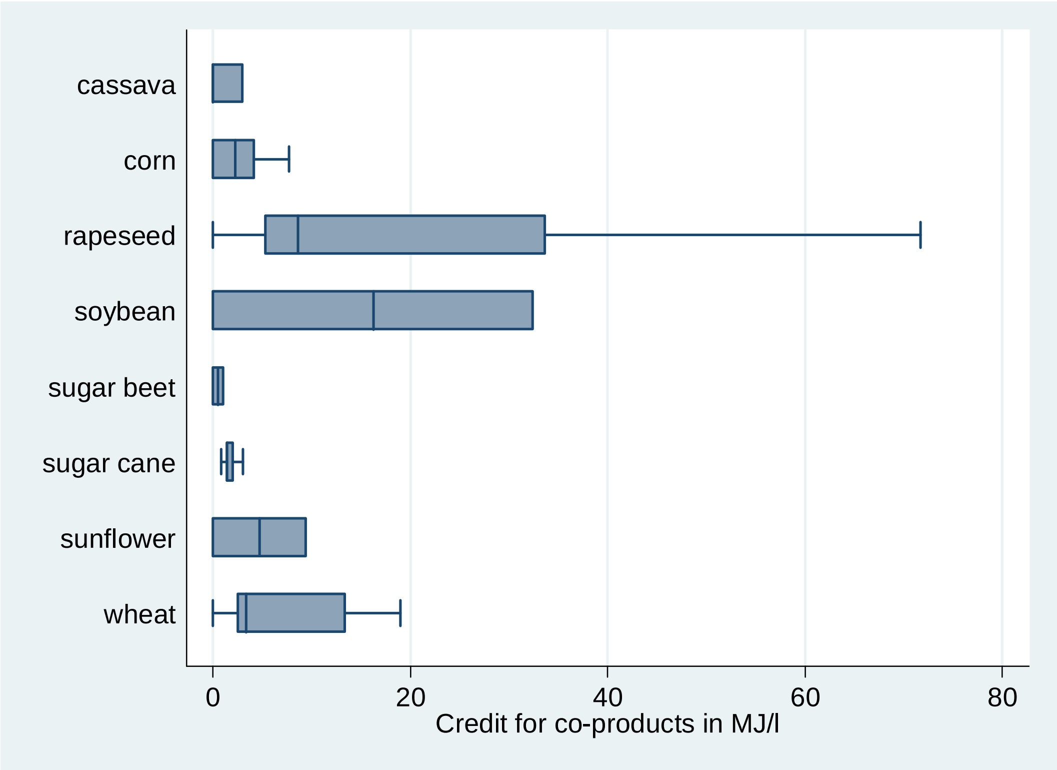

Figure 2: Median and Dispersion Co-product Credit in Fossil Fuel Energy

Generally, the issue of co-product valorization is controversial in LCA, with some studies considering particular co-products as valuable and allocating to them some of the fossil energy used in production, while in others the same co-products are considered to be waste. Some by-products have some value as feedstuffs or fertilizers, but their concentration may be so low as to require an intermediate processing phase, or their use may entail logistical problems, which render them economically unviable. There may be a possible economic valorization, but only in relation to small quantities, that is, a co-product based on a small quantity, is an useless by-product when larger quantities are involved. Economic valorization also depends on potential new outlets or the market price of substitutes.[7]

[7] E.g., it is unclear whether vinasses from wheat and sugar beet pulps produced at concentrations of 10-15% dry material are easily valued by the feed industry or farmers. Typically, some of the very clean CO_2 that is produced with wheat ethanol could be used by the soft drinks industry for carbonated sodas, but this outlet would be quickly saturated. Among the products that could be considered valuable or not depending on levels of production, are glycerin, a co-product of the European biodiesel industry, whose supply may exceed demand. The use of rapeseed cake as a feed for livestock production is dependent on the price of soybean cake, which is driven by exogenous factors such as Asian demand.

Also, choosing to allocate energy use as a proportion of the physical volume of each output, or of its energy content, affects the overall results. Although the more recent studies tend to use the "displacement method", which is seen as being less arbitrary, it is still necessary to make some assumptions (Shapouri et al., 1995).[8]

Fossil energy consumption in agriculture. Many of the differences in the results for NEV across studies stem from the different assumptions made regarding energy consumption via agricultural inputs. There is large variability in both agricultural yields and amounts of inputs per hectare. Nitrogen, for example, accounts for a large share of the energy consumption in agricultural production: there are huge variations in both application rates (kg/ha) and energy content (MJ/kg) across studies. The energy consumed in terms of nitrogen use is a major driver of overall fossil energy consumption in agricultural production. This applies particularly to sugar cane based ethanol, but also to some extent to rapeseed based biodiesel (Figures 3a and 3b).

Other inputs that contribute to the total energy consumed are the fossil fuels (gasoline, diesel and fuel, the last term being used mainly in non-American studies). Again, input/output coefficients for fossil fuels differ a lot across studies. The variation in the unit usage of potassium and phosphate is also high across studies even though these fertilizers account for a smaller share of the overall energy consumption. Labor, a variable that includes[9] custom work and human labor (caloric intake by farm workers is considered in a handful of studies) is included in the energy consumption of the agricultural phase (Figures 3a and 3b).

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[8] E.g., assume that a study on wheat ethanol takes account of the straw used to provide energy in the processing phase; this might affect assumptions about the extra chemical fertilizers required to replace the soil nutrients exported with the straw.

[9] Here we use the same aggregation of heterogenous forms of energy as the one used by Farrell et al. (2006).

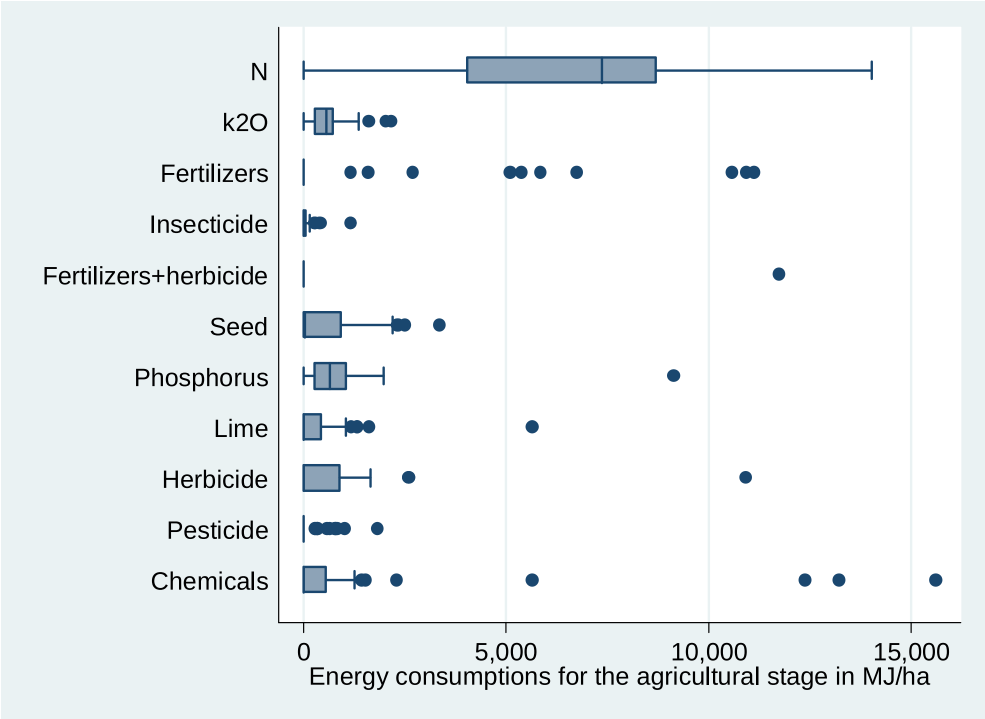

Figure 3a: Energy Consumption of Nitrogen and other Inputs, Median and Dispersion across Studies.

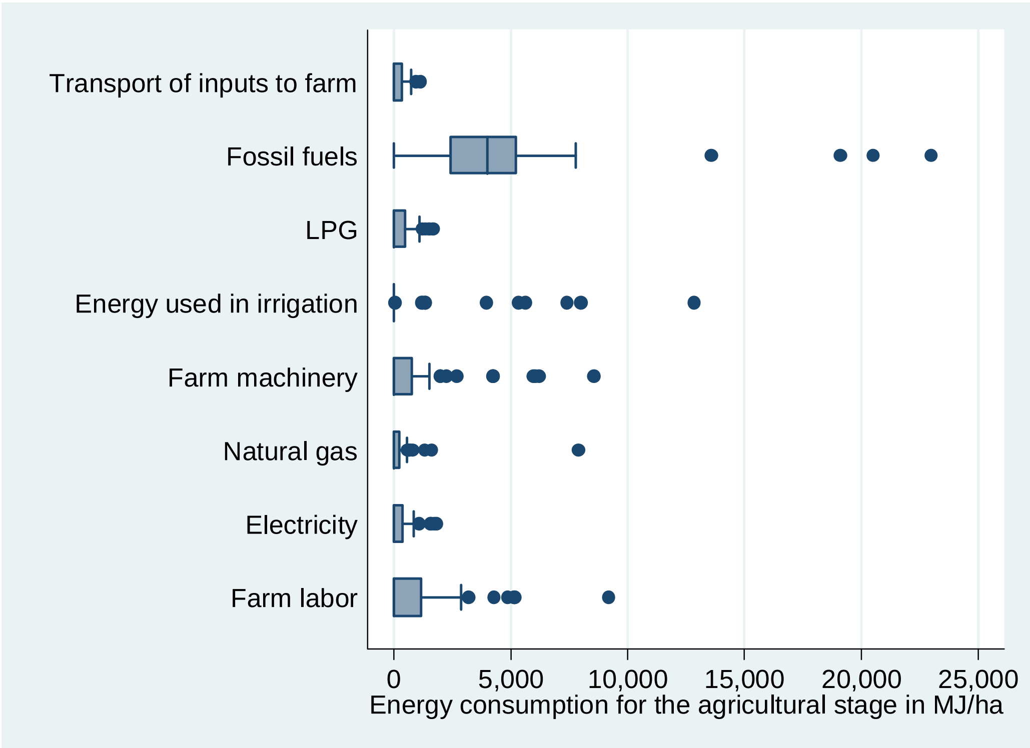

Figure 3b: Energy Consumption of Nitrogen and other Inputs, Median and Dispersion across Studies (continued)

Sources of variation in results for industrial processing. Once we control for type of feedstock (i.e. agricultural yield in kg/ha, refinery yield in liter/kg of feedstock, volumetric yield in liters/ha), estimates of conversion factors and yields vary less across studies in relation to the industrial processing phase (see Figures 4 and 5). In the biorefinery phase, there is intrinsic convergence of coefficients caused by the physical starch, sugar and oil content in the agricultural raw material. The biggest variation is found in processing yields for rapeseed. Overall, yields of biofuel in volume per hectare of corn show little variation across studies, and only limited variation in relation to sugar cane and rapeseed. Because of the variations in energy content, there are large differences in overall energy output per hectare for rapeseed based biodiesel.

Direct use of primary energy accounts for the largest share of energy consumption in the processing phase (Figure 6). Because the coefficients of energy use differ, particularly the use of coal in studies on US ethanol, primary energy use also differs significantly across studies.

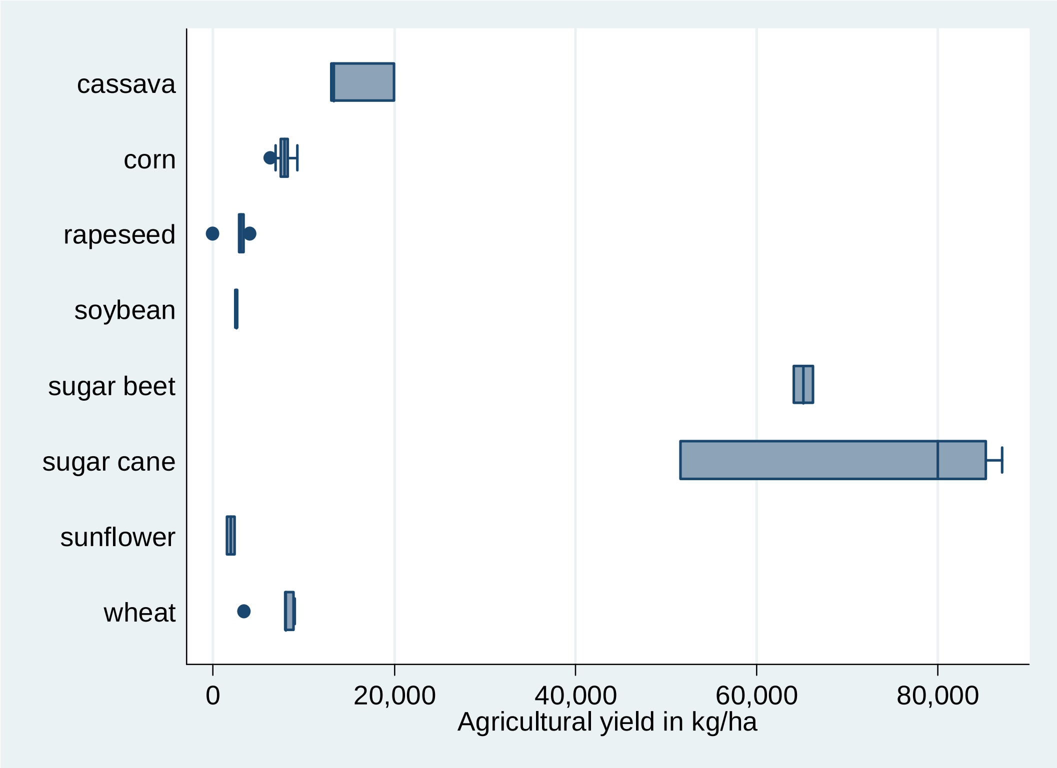

Figure 4: Median and Dispersion in Agricultural Yield per Feedstock

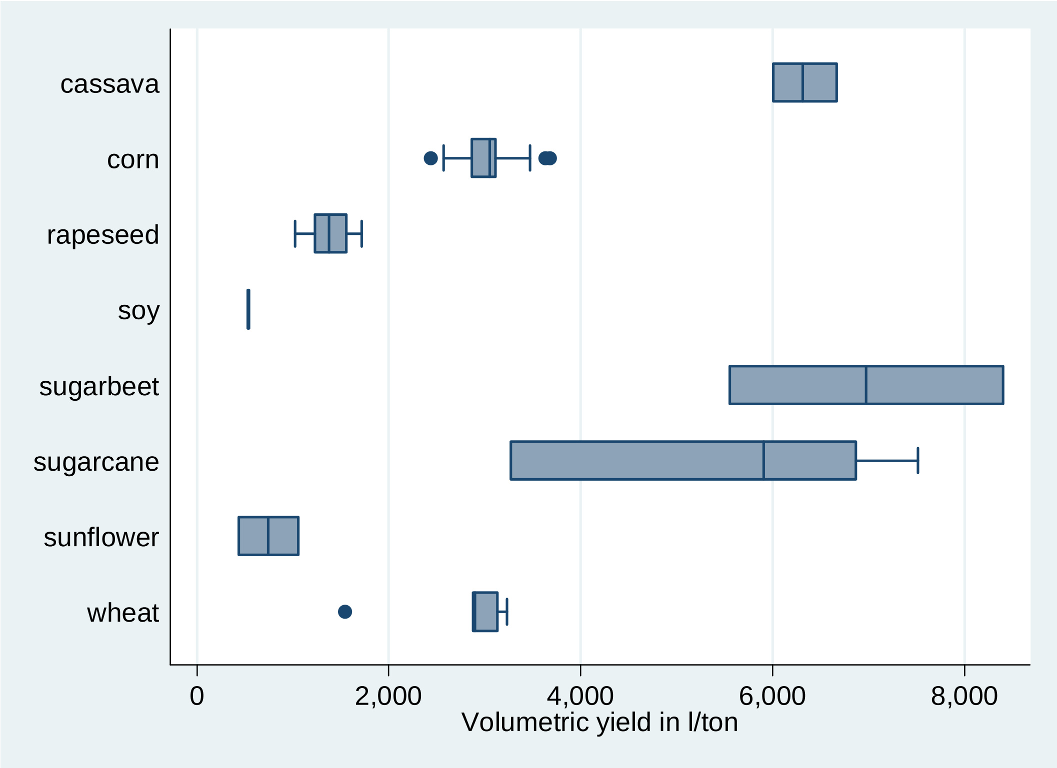

Figure 5: Median and Dispersion in Refinery Yield per Feedstock

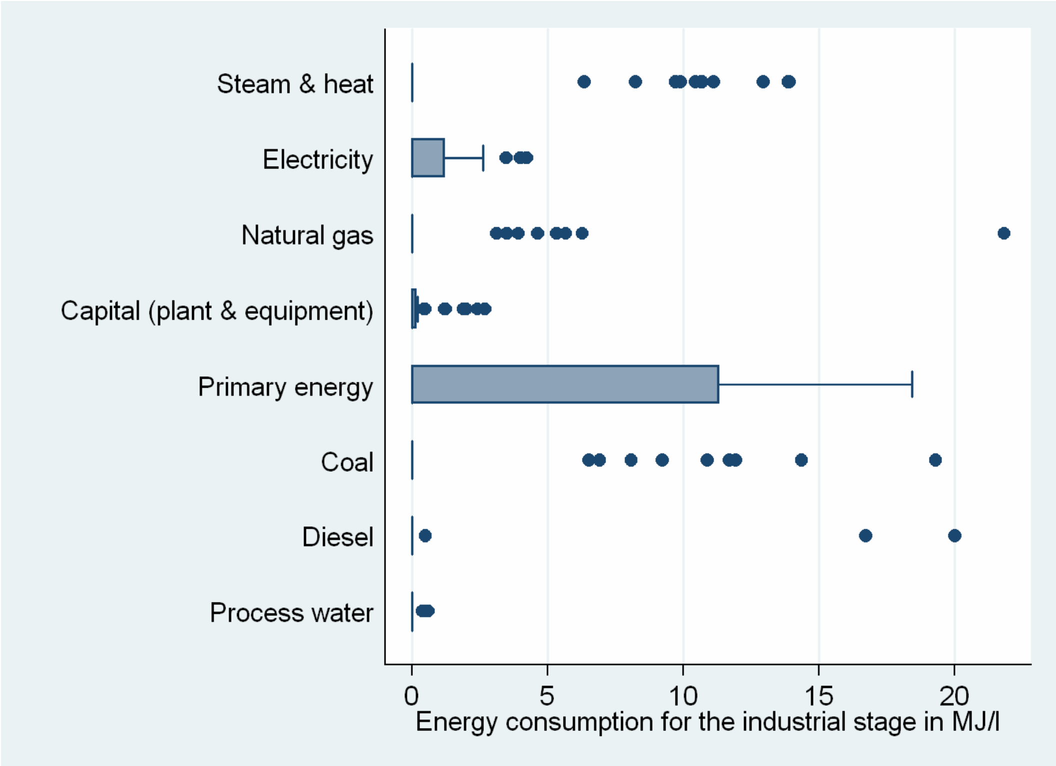

Figure 6: Energy Consumption, Industrial Processing: Median and Dispersion across studies

4. Meta-analysis

The meta-analysis allows us to disentangle the influences of different explanatory variables and approaches on the NEV results in our sample of studies. This method is not without criticisms, which are well discussed by Nelson and Kennedy (2009). They identify problems such as heteroskedasticity and correlated observations, issues that we attempt to minimize by using discrete variables and appropriate estimation techniques (e.g. heteroskedasticity is corrected by computing White-corrected standard errors; see White, 1980). Using the Hadi test, we also exclude outliers from our sample. Another criticism often raised against meta-analysis is that it may combine estimates that are not actually comparable. Examples would include the combination of studies based on different feedstocks or including different explanatory variables. However by controlling for these differences, the meta-regression method allows us to explore whether different settings yield systematically different NEV results.

In meta-regressions, the variance in individual estimates is explained by a set of right-hand side variables, which quantify the different attributes in each study. Here, we estimate the following equation:

$$Yj = \alpha + \beta \boldsymbol{X}j + ej \qquad j= 1, 2, ..., N \tag{1}$$

where Yj is the net energy value reported in study j, $\boldsymbol{X}j$ is the matrix of the meta variables included to explain the variation in net energy value between studies, and β is the vector of the meta-regression coefficients. Among the explanatory variables, we can distinguish between ethanol and biodiesel with dummy variables that replace the constant term. We control for some aspects in the agricultural phase that could affect significantly net energy value. We use several approaches, from a simple to a more complete model. There is indeed a large variability in the degree of detail provided by the different studies regarding the inputs considered in the LCA. The way this was handled was to build rather aggregated variables and to run a regression on the basis of dummies for control, dummy for quartiles, and actual values, and to refine the specification using the statistical significance of the variables. The simpler specifications include only a few explanatory variables, treated as dummies, while the more sophisticated forms include coded variables based on quartiles. In particular, we investigate whether the value applied to nitrogen in the calculation affects the results. We also investigate whether the control for co-products and the approach used for the allocation of co-products influences net energy value.

Table 1 presents the results. Estimated coefficients are reported, as well as their standard errors in parentheses. One star denotes significance of the coefficient at the 10% level or better, two stars denote significance at the 5% level or better, and three stars indicate significance at the 1% level or better.

Column (1) shows the regressions for the net energy value on the two dummies for biodiesel and ethanol. Both show a positive and significant influence on net energy value. In Columns (2) and (3) control dummies for fertilizers (nitrogen, phosphorus, potassium and lime), farm labor, and co-products are equal to 1 if the underlying calculation of net energy value includes these elements. Net energy value is negatively impacted by fertilizers and farm labor consumption during the agricultural phase, while it is positively influenced by co-products. Controls for biodiesel *vs*. ethanol, fertilizers, farm labor and co-products provide good explanations for the variation across studies in net energy value.

Column (3) deals with the method used to allocate co-products. We restrict our estimations to observations that consider co-products in the net energy value calculation. Various methods can be used: displacement allocation, weight allocation, energy allocation, market value allocation. We investigate whether the displacement allocation method provides similar or different results from those obtained using other methods. Some studies use displacement and a second approach to evaluate co-products: one for the agricultural phase and one for the biorefinery phase (see, e.g., Lorens, 1995). In Column (3), the dummy "displacement allocation method for co-products" is set to zero for these observations. The results suggest that using the displacement allocation approach provides a lower net energy value. However, the estimated coefficient is significant only at the 10% level.

Table 1: Meta-regression Results[a]

Dependent variable	Net Energy Value				
Model & feedstock	(1) - All	(2) - All	(3) - All	(4) - All	(5) - Corn
Biodiesel	18.89***	20.08***	31.30***	19.90***	
	(4.63)	(4.32)	(4.37)	(4.44)	
Ethanol	5.14***	10.21***	19.45***	10.40***	
	(1.40)	(3.10)	(2.62)	(2.65)	
Control for fertilizers		-9.60***	-8.32**		
		(3.02)	(3.52)		
Control for farm labor		-7.85***	-1.54	-6.69***	-4.15**
		(1.93)	(2.17)	(1.94)	(1.55)
Control for co-products		10.92***		10.63***	9.77***
		(1.84)		(1.64)	(1.68)
Displacement allocation method for co-products			-4.13*		
			(2.43)		
Nitrogen (MJ/ha): no control				-	-
Nitrogen (MJ/ha): < 1st quartile				-6.86**	3.45**
				(3.07)	(1.34)
Nitrogen (MJ/ha): [1st quart.; 3rd quart.]				-10.19***	-0.43
				(2.75)	(1.52)
Nitrogen (MJ/ha): > 3rd quartile				-14.01***	-7.29***
				(3.05)	(2.35)
Number observations	57	57	37	57	30
R^2	0.415	0.775	0.873	0.816	0.771

[a]Note: Standard errors in parentheses with ***, ** and * denoting significance at the 1%, 5% and 10% level.

Column (4) controls for the value of nitrogen (MJ/ha) instead of using a simple dummy for fertilizers. We define a categorical variable, which takes the value 0 if the underlying study does not include nitrogen and takes the value of 1 to 3, depending on the quartile in which the observation appears (1 for observations in the first quartile, 2 for the second and third quartiles, and 3 for the last quartile). Due to multicollinearity, the first category is dropped from the estimations. Estimated coefficients for the three remaining categories are negative and significant at the 1 percent level and the ranking is as expected: the higher the value for nitrogen in the calculation of net energy value, the higher the negative effect of nitrogen on net energy value.

Column (5) reports the results for corn only. Estimated coefficients for farm labor and co-products are fairly similar to those for the whole sample. Results for the nitrogen quartiles are slightly different: the coefficient estimated for the first quartile is positive and significant, while those for the second and third quartiles are not significant. The ranking remains unchanged.

5. Are there author specific biases?

The same organization or the same author have sometimes published several studies, all included in the sample. Should this author/organization use a peculiar methodology that leads to either particularly high or low results, this may affect the analysis. For example, it is worrying that five of the seven studies that find negative NEV for corn based ethanol involve the same coauthor. At the other end of the spectrum, several studies by researchers associated to a particular laboratory tend to find very high NEV. As already mentioned, the essence of our approach is that studies cannot be excluded from the sample on an *ad hoc* basis; nevertheless, the fact that one particular author may be driving the average results up or down must be kept in mind.

Those studies that specify rather conservative (optimistic) estimates for a particular parameter for a given input, often do the same for other inputs. This phenomenon is highlighted by the apparent correlation among the coefficients of the agricultural production phase for corn in the LCAs (Figure 7). Arguably, this might only mean that there is a natural correlation among different types of agricultural inputs, e.g. between the application rates of nitrogen and other inputs. However, Figure 8 shows that authors who make extreme assumptions about key parameters in the agricultural phase behave similarly in assumptions related to the processing phase although there is no good reason why these variables would be correlated.[10] Figure 9

[10] A possible explanation is that this correlation is caused by exogenous factors (such as price of energy), which may differ between countries, or over time.

isolates the studies of three authors (denoted a, b, c), who tend to find extreme values for NEV for corn based ethanol in studies on North America (top left panel). Studies involving the same three authors are plotted for the different variables in our sample (other panels in Figure 9). It is noticeable that, even for variables that are unlikely to be correlated, such as the fossil energy content of nitrogen, the energy consumed through farm labor, the co-product credits, or even the conversion yields of corn into ethanol, these three authors choose parameters that are in the low (high) range of the assumptions from the whole sample of studies.

The recent efforts for standardized LCAs using ISO certified methodology should help removing the heterogeneity in the assumptions made by authors/organizations.

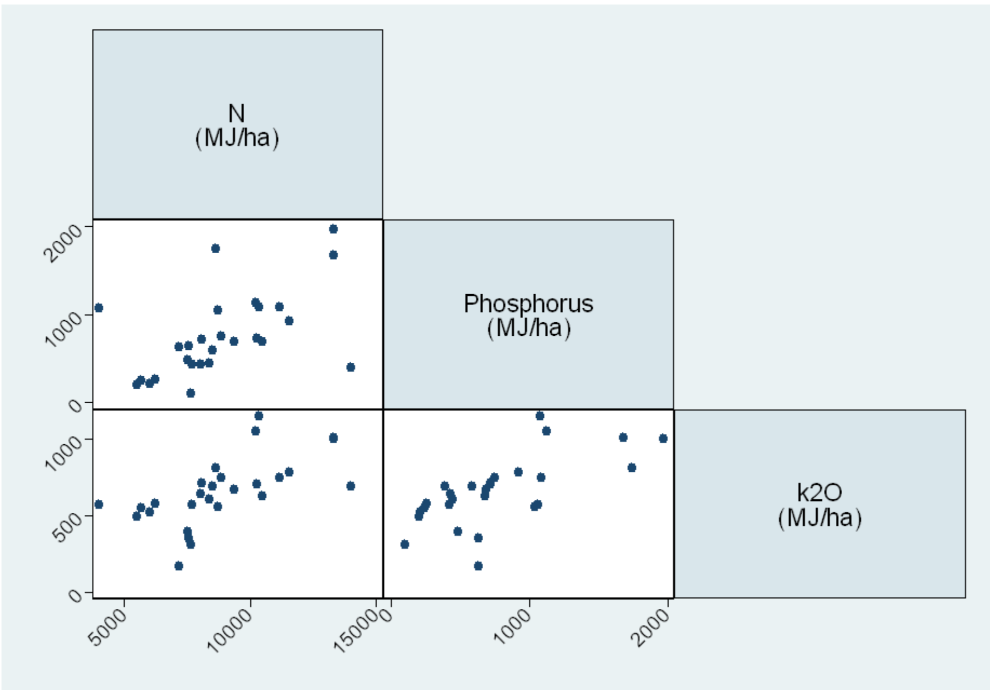

Figure 7: Correspondence between High and Low Assumptions regarding Key Parameters across Studies

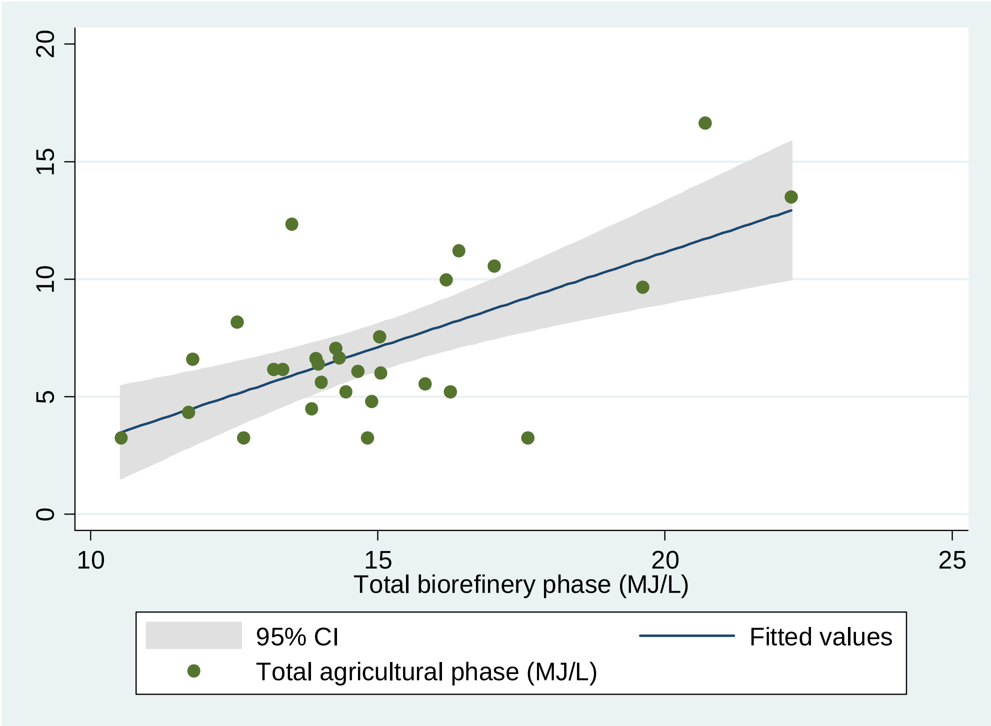

Figure 8: High and Low Assumptions regarding the Agricultural and Processing Phases

Figure 9: Location of Studies in relation to Selected Explanatory Variables

6. Conclusion

The controversy in many OECD countries over public policies that encourage -- and to a large extent have triggered -- the development of biofuels, points to the need for cost-benefit analyses. Assessing the net reduction in GHG emissions is a central component in the benefits of biofuels. The recent decisions of both the EU and the US to impose that biofuels achieve minimal GHG savings in order to benefit from public support also stress the need of robust methodology for measuring net emissions. However, recent findings on non-CO_2 gases add a new dimension to the controversy over net GHG savings. How to account for indirect emissions caused by land use changes has also become a controversial issue.

Large differences in the benefits of biofuels can be observed between studies, even when one does not address the complex issues of land use changes, and the extra layer of controversy related to the estimation of net emissions of high global warming power gases. In particular, we observed that results regarding the energy balance of biofuel vary a lot for biofuel produced from a particular feedstock. Because the net energy balance is a building block of the estimates of net GHG savings, this raises the question of the sources of these differences, and how much of the variance in the results could be solved by standardization of life cycle analysis methods.

Focusing on the Net Energy Value of biofuels, our aim was not to try to harmonize these different methods in an attempt to find a “true” value for the net energy balance of biodiesel and bioethanol, but rather to assess the sources of the large variations in results between studies. We gathered a sample, with as little selection bias as possible, of the many published studies in this area and treated the results to make them comparable (i.e. expressed in the same units).

Descriptive statistics make it possible to provide an assessment of the average and the variance in NEV for biofuel produced from different feedstocks. They also enable assessment of the main sources of the variations in the results for NEV. Meta-analysis shows that these results are highly dependent on key variables, such as type of feedstock or nitrogen and labor consumption levels observed (or assumed) in agricultural production. The fact that within our sample, various authors tend to make assumptions about the coefficients that systematically are in either the low or the high range of possible figures, suggests that there might be an author effect.

The assumptions regarding the fossil fuel credits assigned to co-products are also important determinants of the final results for NEV. Ongoing standardization of the LCA methodology will facilitate the resolution of some of the more major controversies and should narrow the range of results for NEV. Inevitably, there will be some grey areas in terms of what can and should be taken account of as co-products because their value is dependent on production levels and the economic environment. And, because co-products play such an important role in the overall assessment of net energy savings, it is unlikely that results will converge completely even with a more standardized LCA methodology.

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