Towards a Genuine Sustainability Standard for Biofuel Production

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Abstract

Sustainability standards for biofuel production calculated via life cycle accounting (LCA) require a certain reduction in greenhouse gas (GHG) emissions relative to gasoline. Recently it has been shown that LCA gives biased results and should be extended to incorporate indirect land use change (iLUC). We show that even including iLUCs, LCA is still biased and distorted because it is based on GHG emission and uptake calculations, which assume economic values only if (i) the environmental price of carbon is constant over time and (ii) the social discount rate (SDR) equals zero. We offer a sustainability standard free of these restrictions, expressed in terms of a range of SDRs and a maximal GHG payback period. Applying our methodology to Brazilian and U.S. data, we find that in Brazil conversion to biofuel production of two land types is genuinely sustainable, i.e., satisfies our sustainability standard, whereas in the United States no land type satisfies our criterion. Furthermore, the social value of CO_2e savings by having the ethanol production from 12.8 million hectares of U.S. corn be produced in Brazil instead may be as high as $817.7 bil.

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"Some people say ethanol is like cholesterol: there is a good one and a bad one. The good ethanol helps clean up the planet and is competitive. The bad ethanol depends on the fat of subsidies." President Lula, Brazil 02/06/2008.

Life-cycle accounting (LCA) analyses of greenhouse gas (GHG) emissions found that U.S. corn-based ethanol decreases emissions 20 percent over 30 years compared with using gasoline (Farrell et al. 2006; Argonne 2008). As a consequence, the Energy Independence and Security Act of 2007 (EISA) requires ethanol production to reduce emissions by at least 20 percent.[1] In contrast, Searchinger et al. (2008) found that substituting U.S. corn-based ethanol for gasoline increases GHGs by 93 percent over 30 years when indirect land use changes (iLUC) are accounted for (i.e., the conversion of uncultivated land in the United States and the rest of the world such as forest and grassland to cropland and so replace U.S. cropland diverted to ethanol). The U.S. Congress had explicitly required the assessment of iLUC in the EISA statute, requiring the Environmental Protection Agency (EPA) to assess the "significant indirect emissions such as significant emissions from land use changes." EPA was to report by October 2008 but has not yet done so.[2]

This situation raises several policy issues that the EPA should address: Should the 20 percent emission savings be lowered or should ethanol production be banned altogether? Should regulations require GHG emissions to decline over 30 years or over a longer (or shorter) period? If GHG emission eventually decreases, does it mean that society benefits from ethanol production? None of these questions can be adequately addressed by LCA -- with or without iLUCs. This is because LCA is based on GHG balance calculations, i.e., comparing overall GHG emission with overall GHG uptake over periods of time (e.g., 30 years), and such balances interpreted as economic benefits or costs only if (i) the (environmental) price of carbon is constant over time and (ii) the social discount rate (SDR) is zero. Both conditions are inappropriate: the price of carbon increases over time as long as atmospheric GHG concentration increases (with its ensuing climate change induced threats); and a positive (though not necessarily constant) discount rate is required to determine intergenerational tradeoffs when economic growth is expected to persist (even at a reduced rate). Existing sustainability standards (with or without iLUC) are therefore biased and distort the ensuing policy recommendation. In this paper we develop a cost-benefit test for biofuel production which relaxes these assumptions and allows for a changing carbon price and a positive SDR, thereby offering a genuinely sustainable standard for biofuel production.

Our test is represented by a sustainability standard expressed in terms of a social discount rate (SDR) r and a GHG payback period n, holds for any non-decreasing carbon price series and is calculated from readily accessible data. The SDR has been the focus of the debate surrounding the Stern Review (Stern 2007). By GHG payback period we mean the time before the overall GHG emission and uptake balance each other out. Putting a limit (n) on this period is motivated by recent concerns that the more damaging consequences of global warming are those associated with abrupt climate change (Alley et al. 2003, Stern 2007, IPCC 2007). Using Searchinger et al.'s (2008) data as an illustration, we find that two land types in Brazil pass the sustainability standard for any SDR r of 6 percent or less (in the range considered, e.g., by Cline 1992, Stern 2007, Nordhaus 2007, Weitzman 2007 and Dasgupta 2007) and any GHG payback period n of 15 years or less. On the other hand, no biofuel land conversion in the U.S. passes our sustainability standard with an SDR above 1.63 percent and payback period below 61 years.[3] Our test is conservative as it requires that the biofuel crop is produced on land previously not in crop production (i.e. converted land), thus avoiding controversy over how to measure iLUCs[4] and impacts of biofuels on food prices.[5]

We also do an analysis of the global social gains that would occur if U.S. ethanol was produced in Brazil instead. The social value of CO_2e savings by having the ethanol production from 12.8 million hectares of U.S. corn be produced in Brazil instead may be as high as $817.7 bil.

2. Costs and benefits of biofuel land conversion

The conversion of land from an original (pre-conversion) use to ethanol production entails both emission and uptake (sequestration) of GHGs (mainly CO_2, nitrous oxides and methane, expressed in CO_2 equivalent units and referred to as CO_2e). These emissions and uptakes depend on the soil type, its original use, the biofuel crop, and vary across geographical locations. In the application below, we consider a variety of pre-conversion uses and land types in Brazil and the United States (see Table 1). Emission occurs mostly at the conversion year, while uptake evolves gradually over time. Accordingly, let C_0 represent CO_2e emission at the conversion time $t = 0$, measured in metric ton per hectare (MT ha^{-1}), and let $c_1 = c_2 - c_3$ represent the net annual flow of CO_2e uptake (emission if negative) of the biofuel crop from $t = 1$ onward, measured in MT per hectare per year (MT ha^{-1} year^{-1}). Here c_2 represents annual CO_2e uptake by the biofuel crop and c_3 is annual CO_2e uptake by the pre-conversion use (e.g., forest or grassland uptake of CO_2e) foregone due to conversion.

Land conversion to ethanol production is beneficial vis-à-vis GHGs effects if the emission cost is smaller than the sequestration benefit. Evaluating the cost and benefit requires expressing CO_2e emissions and sequestrations in monetary terms at each point of time and discounting to a particular time period, say the conversion year. The net balance of CO_2e, i.e., overall sequestration minus overall emission, assumes an economic value when (a) the price of carbon is constant over time, and (b) the social discount rate is zero. Both conditions are at best questionable. The carbon price reflects the cost of atmospheric GHG concentration and is expected to increase as long as the latter increases. The SDR entails intergenerational tradeoffs and should be positive (though not necessarily constant) if economic growth is expected to persist (even at a reduced rate).

To obtain a better grasp of the problem at hand it helps to view biofuel land conversion as a public project for which the investment cost is due to the CO_2e emission at the time of conversion (C_0) and the benefit comes from the net flow of carbon sequestration (c_1). Testing whether the project is desirable requires (i) expressing the CO_2e sequestrations in monetary terms, (ii) calculating the present value of the sequestration flow, and (iii) comparing with the upfront emission cost. Simply calculating CO_2e balances distorts this test and may reverse its outcomes.

Expressing CO_2e emission or sequestration series in monetary terms require comparable carbon price series; evaluating the present value of a monetary series entails discounting. We discuss discounting and carbon pricing in turn.

2.1 *Discounting*

It is difficult to overstate the role played by the social discount rate in cost benefit analyses of public projects. And it is even more difficult to do so when the project under consideration extends into the distant future, as is the case when dealing with climate change consequences of GHG emissions. A case in point is the recent controversy surrounding the Stern Review (Stern, 2007), which revolves around the parameters of the SDR (Dasgupta 2007, Nordhaus 2007, Weitzman 2007). The SDR is often represented in the form $r = \delta + \eta g$, where δ

is the pure (utility) discount rate, η is the elasticity of marginal utility of consumption and g is the growth rate of per capita consumption. This expression separates between the two main motives of discounting, namely impatience (δ) and economic growth (ηg). While discounting for impatience (or pure time discounting) is reasonable for private investments, it is harder to justify in public investments, as was forcefully argued by Ramsey (1928) and Pigou (1932). Yet, assuming $\delta = 0$ does not on its own imply a zero SDR, since the second term (ηg) is in general positive. An average person today is about twice wealthier than his grandparents of two generations ago. It is thus unreasonable to compare a unit of our grandparents' income on a par with a unit of our income (as implied by a zero discount rate) – if only due to diminishing marginal utility which implies that this income unit is worth more to our (much poorer) grandparents (then) than to us (now). If we expect economic growth to persist in the long run (even at a reduced rate of around 1 percent), we should allow for a positive SDR. The above-mentioned controversy revolves on the magnitude of the SDR – not whether or not it should be zero.

Yet, standard LCA and Searchinger et al (2008, online supporting materials p. 16) use a zero discount rate, explaining this choice as follows:

> "... the choice of a discount rate, and even the decision whether to select a constant discount rate, a varying but continuous discount rate, or a discontinuous discount rate, reflects an enormous range of technical and policy judgments... These are matters of great uncertainty that the selection of a discount rate has to treat as certain. The incorporation of a discount rate directly into the model to count today the value of future reductions therefore has great potential to obscure the actual effect on emissions of biofuels for policy-makers in the near-term"

Indeed the quotation lists nicely the various concerns associated with discounting public projects that extend into the distant future. Yet it leaves one puzzled as to how a zero discount rate addresses any of these concerns. Economists have long been troubled by the adverse implications of committing to a constant discount rate (see, the review by Groom et al. 2005), and the numerous approaches offered in the literature are based in one way or another on declining discount rates (e.g., Chichilinsky 1996, 1997, Weitzman 1998, 1999, Arrow 1999, Cropper and Laibson 1999, Karp 2005, Dasgupta and Maskin 2005). Committing to a zero discount rate has rarely been advocated because it resolves none of the limitations of a constant rate specification, and there is nothing magical about zero that makes it less arbitrary than, say, a 2 percent discount rate when economic growth is expected to persist (even at a reduced rate).[6]

Our approach here is to allow for a plausible range of SDRs, such that the cost-benefit criterion (developed below) applies to any SDR in this range. In the context of GHG emission - induced climate change, the parameters assigned to δ, η and g give rise to SDR values between 1.4 percent (Cline 1992, Stern 2007), 5 – 6 percent (Nordhaus 2007, Weitzman 2007) and even higher. This suggests an SDR range of up to 6 percent.

Because the cost of land conversion (due to emission of GHG) occurs at the conversion time and the benefit (due to GHG uptakes) evolves gradually over time, assuming a zero SDR is more favorable to land conversion as compared with the case when a positive SDR is assumed. Thus, Searchinger et. al's (2008) conclusions against land conversion remain valid also under a positive SDR. However, it is possible that land conversion to biofuel production is found beneficial under a zero SDR but not under a positive SDR, as the empirical example below, based on Searchinger et. al's (2008) data, demonstrates.

2.2 *Carbon pricing*

The carbon price at time t, denoted P_t, is the shadow price of atmospheric GHG concentration. This price represents our willingness-to-pay to remove one metric ton (MT) of CO_2e from the atmosphere (or, alternatively, for preventing the emission of one MT of CO_2e) at time t. This would have been the price of a permit to emit one MT of CO_2e during year t had efficient markets for such permits been present. For a number of reasons such efficient markets do not exist and we can only use estimates of P_t.[7] Possible estimates are the *carbon tax* series generated by integrated assessment models (IAMs), such as Nordhaus' DICE (Nordhaus and Boyer 2000) or the PAGE model used by Stern (2007). Evidently, these price series vary from IAM to IAM (see, e.g., Figure 1 in Nordhaus 2007, p. 699), so that tying our analysis to a particular series will undermine the robustness of our results. Our cost-benefit test, therefore only relies on the property that P_t does not decrease with atmospheric GHG concentration, hence with time (as long as GHG concentration does not decrease with time). It is convenient to use the normalized carbon price $p_t = P_t/P_0$, which (for a non-decreasing P_t series) satisfies $p_0 = 1$ and $p_t \geq 1$, t=1,2,… .

3. A genuine sustainability standard

Given a normalized carbon price series $p_t \geq 1$, $t = 0,1,2,\ldots$, and an SDR r, the present value of a net CO_2e uptake process c_t, t=1,2,…., is $\sum_{t=1}^{\infty} p_t c_t (1+r)^{-t}$. For the case under consideration, the sequestration flow is constant, $c_t = c_1$, and the present value specializes to $c_1 \sum_{t=1}^{\infty} p_t (1+r)^{-t}$. Invoking $p_t \geq 1$ gives $c_1 \sum_{t=1}^{\infty} p_t (1+r)^{-t} \geq c_1 \sum_{t=1}^{\infty} (1+r)^{-t} = c_1 / r$. The cost of the (mostly upfront) emission C_0 at the conversion time is $p_0 C_0 = C_0$. Thus, $c_1/r \geq C_0$, or equivalently $r \leq c_1/C_0$, ensures that biofuel land conversion pays off (vis-à-vis its GHGs effects). We conclude that c_1/C_0 constitutes an upper bound on the set of SDRs r for which the present value of the CO_2e sequestration flow does not fall short of the cost of emission for *any* non-decreasing carbon price series P_t. We thus require that

$$\frac{c_1}{C_0} \geq \bar{r}, \tag{1}$$

where $\bar{r}$ is an upper bound on the set of plausible SDR values. With the guide of the above-mentioned debate about the Stern Review, $\bar{r}$ = 6 percent constitutes a plausible SDR range.

The various land conversion situations in Table 1 are characterized by C_0 and c_1. If condition (1) is satisfied, then the benefit generated by the GHG uptake flow (at the constant rate c_1) exceeds the cost inflicted by the GHG emission C_0 (that occurs at the conversion time) for *any* SDR $r \leq \bar{r}$ and for *any* non-decreasing carbon price series P_t. Put differently, the present value of the net flow of CO_2e uptakes will *eventually* outweigh the cost of the upfront emission C_0 for any SDR at or below $\bar{r}$ and for any non-decreasing carbon price series P_t.

However, this *eventual* state of affairs may take a long time to occur—too long to be of much use if in the meantime the GHG-induced climate change has caused substantial damage. This concern stems from alarming evidence that some of the catastrophic consequences of global warming will be inflicted abruptly at dates that cannot be predicted a priori (Alley et al. 2003, Stern 2007, IPCC 2007). The risk associated with abrupt climate change is represented by a hazard rate function that depends on the atmospheric concentration of GHGs and measures, at each point of time, the risk of immediate occurrence of a catastrophic event given that the event has not yet occurred (see Tsur and Zemel 1996, 1998, 2008). Since most of the GHGs emission induced by land conversion occurs upfront and the compensation in the form of GHG uptake evolves gradually over time, initially land conversion contributes positively to atmospheric GHG concentration, thereby increasing the occurrence hazard of abrupt climate change. This calls for placing a limit on the time it takes for the accumulated GHG uptake to balance out the upfront emission. For example, Searchinger et al. (2008, p. 16 online supporting materials) suggest a time limit of about 30 years, stating that

> "... from a global-warming perspective, crop-based biofuels are generally viewed as at most a short-term strategy to provide immediate reductions in greenhouse gasses as the world pursues more transformative energy strategies… Emission reductions during early years will also be more expensive than maintaining those reductions in the long-term once technologies have evolved. For these reasons, we believe the net impact on greenhouse gas emissions over a 30 year period provides a reasonable test of greenhouse impacts....……The IPCC has specifically warned against delaying emissions reductions because of the risk of harsh, long-term, unavoidable impacts without immediate reductions. Strategies that increase emissions over a 30 year period require offsetting additional reductions over that period to achieve near-term goals, and those additional offsetting reductions must be achieved at the highest point of the cost curve."

The Gallagher Report (Renewable Fuels Agency 2008) requires a shorter payback period of 10 year. As in the case of the SDR, there is no objective prescription that justifies a particular time limit and more than a shred of value judgment together with subjective risk assessments are needed. We now incorporate a payback time limit and obtain our sustainability standard.

Let n represent a (pre-specified) maximal period allowed for the accumulated GHG uptake (nc_1) to compensate for the upfront emission (C_0). Then, we require that $nc_1 \geq C_0$, which together with condition (1) gives our sustainability standard

$$\frac{c_1}{C_0} \geq \max\left\{\bar{r}, \frac{1}{n}\right\} \tag{2}$$

in terms of an SDR upper bound $\bar{r}$ and a GHG payback time limit n. We say that land conversion to biofuel production is *genuinely sustainable* if it satisfies (2). Thus, a land conversion situation (characterized by C_0 and c_1) is genuinely sustainable if c_1/C_0 does not exceed $\bar{r}$ and C_0/c_1 does not exceed n. We turn now to check whether production of corn ethanol in the U.S. and sugarcane ethanol in Brazil are genuinely sustainable.

4. Ethanol production in the United States and Brazil

Table 1 presents C_0, c_1, c_1/C_0 and C_0/c_1 associated with converting various land types for sugarcane ethanol in Brazil and corn ethanol in the United States. The emission and uptake calculations are based on data from Searchinger et al. (2008). We see that converting a hectare of Cerrado in Brazil for sugarcane ethanol production is genuinely sustainable at any SDR at or below 6.78% and any n at or above 15 years – well within the [0,6%] SDR range, which accommodates most commentators of the Stern Review, and the time limit advocated by Searchinger et al. (2008). Converting grassland for sugarcane ethanol production in Brazil is genuinely sustainable at any SDR at or below $\bar{r} = 23.93\%$ and any time limit at or above $n = 4$ years.

In the United States, on the other hand, no land type conversion to corn ethanol production is genuinely sustainable at any SDR above 1.63% and any n below 61 years. Under the SDR upper bound of 6 percent and the payback period of 30 years, the conversion of two land types in Brazil are genuinely sustainable while in the United States, no land type conversion possesses this property.

It is worth emphasizing that, consistent with Searchinger et al.'s (2008) extension of LCA to account for indirect land use effects, our sustainability standards require that conversion to biofuel must be from land currently *not* in food production. This is so because converting land from food production (e.g., corn for animal feed) into ethanol production entails some conversion emission but no net sequestration, since the GHG withdrawal of the ethanol corn (c_2) is the same (or very similar) to the foregone withdrawal of the feed corn (c_3), as revealed by LCA calculations (see, for example, Table 1 of Searchinger et al. 2008, which shows that when a ethanol corn displaces feed corn the GHG saving is negative). Our sustainability condition, thus, requires that conversion to biofuel production must use idle land or land not in agricultural use. This feature makes our standard conservative as it avoids direct effects of biofuels on staple food prices and avoids controversy over how to measure iLUCs.

Finally we note that the results in Table 1 possibly understate the potential advantage of ethanol production in Brazil relative to production the United States due to the difference in potential yield increase in both countries. If the state-of-the-art technology used for corn production in the United States were applied to sugar cane production in Brazil, sugar cane production could be significantly increased (by 30 percent according to Wiebe 2008, and by 2-3 fold according to Kishore 2008).

5. Policy simulations

We simulate the social value of GHG savings if all ethanol production in the United States was required to be produced in Brazil. This may seem as a hypothetical exercise but actually it has some realistic aspects. It is widely agreed that if there were no subsidies for feedstocks or ethanol in the United States in the past (and no import tariff), then it is highly likely that ethanol would be imported into the United States instead of produced domestically. Furthermore, U.S. ethanol production is expected to double by 2015 and the simulation provides a first order approximation of the welfare gain associated with producing the ethanol in Brazil instead. Finally, a regulation that results in U.S. ethanol production shifting to Brazil is similar to the current 0,1 sustainability thresholds employed by the United States and under consideration in the European Union.

We simulate a reversal of the Searchinger et al. (2008) exercise where the ethanol currently produced from the 12.8 million hectares of corn in the United States are produced in Brazil instead. The CO_2e costs reported in Searchinger et al. (2008) are now reversed and become savings. We assume the ethanol can only be produced on converted land and must be on grassland or the Cerrado. Because the ethanol yield per hectare is about twice that in Brazil compared to the United States, only 6.4 mil. hectares of land need to be converted into ethanol production in Brazil in order to produce current U.S. ethanol production levels.[8] The benefit due to saving the CO_2e emission in the United States is ($\$_{t=0}$ ha^{-1})

$$B^{USA} = P_0 C_0^{USA} - \sum_{t=1}^{\infty} P_t C_1^{USA} / (1+r)^t$$

The cost per hectare associated with the CO_2e emission in Brazil is ($\$_{t=0}$ ha^{-1})

$$C^{Brazil} = P_0 C_0^{B} - \sum_{t=1}^{\infty} P_t C_1^{B} / (1+r)^t$$

The overall benefit is given by

$$12.8\times10^6 \times B^{USA} - 6.4\times10^6 \times B^{Brazil} = 12.8\times10^6 P_0 \left[C_0^{USA} - \frac{1}{2} C_0^{B} + \left(\frac{1}{2} C_1^{Brazil} - C_1^{USA} \right) \sum_{t=1}^{\infty} \frac{p_t}{(1+r)^t} \right]$$

where it is recalled that $p_t = P_t/P_0$, $p_0 = 1$ and $p_t \geq 1$. Since (see Table 1)

$\frac{1}{2} C_1^{Brasil} - C_1^{USA} = 18/2 - 1.8 = 4.2 > 0$ and $\sum_{t=1}^{\infty} \frac{p_t}{(1+r)^t} \geq \frac{1}{r}$, we can bound the above benefit from below by

$$12.8\times10^6 P_0 \left[C_0^{USA} - \frac{1}{2} C_0^{Brazil} + \left(\frac{1}{2} C_1^{Brazil} - C_1^{USA} \right) \frac{1}{r} \right]$$

Results in Table 2 indicate that the world's welfare gain due to change in GHG emissions ranges from a high of $817.7 bil. (grassland under Nordhaus's (2007a) interpretation of Stern's (2007) analysis) to a low of $30.8 bil. (on Cerrado with Nordhaus's (2007a) discount rate). Using

Stern's (2008) price \$48 (30 euro) per tonne CO_2 (p. 9), the social value of having U.S. ethanol produced in Brazil instead is valued between \$421.3 bil. and \$480.2 bil., a significant savings.

If the carbon price P_t increases linearly in time for about a century at a slope α and then levels off, the welfare gains can be more precisely approximated by

$$12.8\times10^6 P_0\left[C_0^{USA}-\frac{1}{2}C_0^{Brazil}+\left(\frac{1}{2}C_1^{Brazil}-C_1^{USA}\right)\frac{1+\alpha}{r}\right].$$

Thus, the figures in Table 2 underestimate the benefit by $12.8\times10^6 P_0\left(\left(\frac{1}{2}C_1^{Brazil}-C_1^{USA}\right)\frac{\alpha}{r}\right)$.

Based on Nordhaus (2007), the slope of the carbon price is approximately $\alpha = 1.36$ or $\alpha = 0.272$ under $r = 1.4\%$ or $r = 5.5\%$, respectively. We find that the benefits presented in Table 2 underestimate the true benefits by \$10.402 billion under $r = 1.4\%$ and by \$0.206 billion under $r = 5.5\%$.

6. Concluding comments

Current sustainability standards for biofuel land conversion adopted by the United States and the European Union are biased – with or without Searchinger et al.'s (2008) extension incorporating indirect land use changes (iLUC). The reason is that these standards are based on CO_2e balance calculations, thus implicitly assume that the price of carbon remains constant over time and that the social discount rate (SDR) is zero. The cost-benefit procedure developed here addresses these shortcomings. We formulate a condition to ensure that the present value of the monetary flow of GHGs uptakes will eventually exceed the emission cost for all social discount rate (SDR) values at or below a pre-specified threshold $\bar{r}$ and all non-decreasing carbon price series. Motivated by risks of abrupt climate change, we also require that the payback period (the time it takes for the accumulated GHG uptake to fully compensate for the upfront emission) does not exceed a pre-specified length *n*. Put together, these conditions form a sustainability standard that can be calculated from readily available data.

Our procedure is not free of value judgment, as it relies on two thresholds: an SDR threshold $\bar{r}$ and a payback period threshold *n*. The former has been the centerpiece of the recent debate surrounding the Stern Review (Stern 2007); the latter is part of existing sustainability standard (see, e.g., the Gallagher Review -- Renewable Fuels Agency 2008). Our procedure uses these thresholds in a way that is consistent with cost-benefit analysis and with the risks associated with abrupt climate change.

The empirical analysis, based on Searchinger et al.'s (2008) data, is illustrative in that we only look at two countries and two feedstocks producing one biofuel. More comprehensive empirical testing should be done on other countries, feedstocks and biofuels to get a better understanding of the sustainability standards offered here. The data underlying our analysis are constantly being updated and an "industry standard" or "best practice" method should be developed over time (just like with standard LCA in the past).

Table 1: Data on GHG emission and uptake for various land types in Brazil and the United States

	C_0	c_1	c_1/C_0	C_0/c_1
Land type	Upfront CO_2e emission (MT ha^{-1})	Net flow of CO_2e uptake (MT ha^{-1} $year^{-1}$)		
Brazil				
Tempef	739.6	14.7	1.98%	50
Tropef	823.9	18.0	2.18%	46
Tropsf	603.8	16.9	2.80%	36
Tempsf	489.9	18.0	3.67%	27
Tropof (Cerrado)	265.3	18.0	6.78%	15
Grassland	75.2	18.0	23.93%	4
United States				
Coniferous Pacific	880.8	-1.2	-	-
Mixed forest	770.8	0.3	0.04%	2700
Broadleaf forest	688.2	-0.5	-	-
Woodland	413.0	1.6	0.39%	259
Coniferous/Mountain	642.3	1.8	0.28%	357
Chaparral	220.2	1.8	0.82%	122
Grassland	110.1	1.8	1.63%	61

Source: Calculated using data from Searchinger et al. (2008).

Table 2: Social value of having U.S. ethanol produced in Brazil

		Cerrado	*Grassland or desert*
Nordhaus on Stern	**r = 1.4%** **P_0 = 81.7**	**$718.2 bil.**	**$817.7 bil.**
Stern	**r = 1.4%** **P_0 = 48**	**$421.3 bil.**	**$480.2 bil.**
Nordhaus	**r = 5.5%** **P_0 = 8.17**	**$30.8 bil.**	**$40.7 bil.**

Source: calculated

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Endnotes

[1] California's low-carbon standard targets additional savings in GHG emissions while the Commission of the European Communities developed a directive for the European Parliament that biofuels emit 35% less GHGs than gasoline.

[2] California's low-carbon standard is also being revised to factor in the impact of biofuels on land use, with the California Air Resources Board to implement the (yet unannounced) rules in April 2009. Meanwhile, the EU has recently ordered the inclusion of iLUCs in the LCA calculation of their sustainability standard, where the outcome is also in abeyance.

[3] The Searchinger et al. (2008) study highlighted the possibility that ethanol from Brazilian sugarcane is an exception: "the extraordinary productivity of Brazilian sugarcane merits special future analysis." Using a different methodology, our study confirms this possibility but only for two land types.

[4] To empirically calculate all indirect effects would be a huge exercise and the chances of getting agreement at the national (let alone international) level would be slim. Our sustainability standard is based on land conversion, thereby sidestepping the controversy over iLUC by assuming it is 100 percent. Standard direct LCA is basically input-output analysis. To include all indirect effects (for land and non-land inputs as well as for output) would require measuring impact multipliers of a linear programming model of the entire world economy.

[5] The iLUC argument overlooks indirect uses of inputs other than land that would also need to be measured as well as "indirect output use effects" - ethanol may not replace gasoline but replace coal instead, giving a credit to ethanol production. Just as Searchinger et al. (2008) showed that it is erroneous to assume that all agricultural production on land diverted to ethanol production is not replaced, it may also be erroneous to assume that all output (in this case, gasoline) is replaced with the ethanol production. In other words, there may be "indirect output use changes" as well. This is ignored in the literature. Oil is generally thought of as "finite" while coal is considered "unlimited in supply", implying that if the supply curve for oil is vertical and the supply curve for coal is flat, then biofuels do not replace any oil but replaces coal instead, which emits 40 percent more CO_2 per BTU than oil.

[6] Some economists argue that CO_2e emissions (or the damages therefrom) cannot be discounted because emissions increase the accumulated stock of GHGs and so the damage done is a cumulative function of GHGs emitted over time. The claim is that the correct measure should be some present value price of each year. This criticism is incorporated in our analysis through the price of carbon – the marginal cost of the GHG stock. If you add to that stock each year, you increase the cost by the carbon price which is incorporated in our analysis.

[7] Efficient markets for emission permits do not exist partly because of the long time span and the vast uncertainties associated with the chain of events that begins at GHG emissions and accumulation in the atmosphere, continues with the effect of GHG concentration on average warming, and ends at damages inflicted by the global warming.

[8] Of the 12.8 mil. hectares of corn devoted to ethanol production, 2.245 mil. hectares are converted *directly* in the United States and 10.555 mil. hectares diverted from existing corn or alternative crops in the United States. Of the latter, 8.572 mil. hectares are *indirectly* converted from forests and grasslands in the United States and rest of the world, while 1.983 mil. hectares are *indirectly* diverted from alternative crops in the United States and the rest of the world. Having Brazil produce this ethanol instead, there are savings in upfront CO_2e emissions on 10.817 mil. hectares plus the added value of annual CO2 sequestration of the 2.245 mil. hectares that is converted back to forests in the United States. However, there is a loss of annual net sequestration of the land devoted to ethanol production in the United States. Brazil requires only half the land to produce the same amount of ethanol (6.4 mil. hectares) and obtains a higher annual net sequestration of CO_2e from ethanol as well.