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A Practical Approach for Policies to Address GHG Emissions from Indirect Land Use Change Associated with Biofuels

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This Technical Paper was commissioned by Greenergy as a first step in developing a practical approach to quantifying the ILUC emissions associated with different biofuel feedstocks within the context of changing patterns of global land use. The research was undertaken independently by Ecometrica and reviewed by Imperial College. Unless otherwise stated, the content of this document does not represent the official position or views of Greenergy.

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Summary

Recent estimates of indirect land use change impacts associated with biofuel expansion have used forward- casting models to predict the effects of changes in feedstock use upon agricultural commodity markets and land use decisions. The predictive reliability of such models is highly questionable and their application provides a limited basis for practical solutions either by the biofuel industry or by policy makers.

We propose a three step approach based upon actual land use change data, leading to progressive definition and attribution of responsibility for LUC over time:

Step 1	Estimation of LUC emissions associated with marginal changes in output of commercial agricultural crops based on a share of actual LUC emissions (using standard allocation methods)
Step 2	Separation of direct and indirect emissions, such that total LUC emissions = directly attributed emissions + indirect emissions (to avoid double-counting)
Step 3	Progressive attribution and acceptance of responsibility towards direct effects by each sector and producer, thus reducing the residual pool of indirect emissions

Using this allocation based approach, we provide initial estimates of LUC emissions attributable to biofuels (and to commercial agriculture in general). Marginal LUC emissions for various biofuels for the period 2000 to 2005 ranged from 10 to 45 g CO_2 / MJ. Whereas, mean LUC emissions[1] for the same biofuels for this period ranged from 0.9 to 4 g CO_2 / MJ. We expect that the application of environmental safeguards to protect high carbon ecosystems, as parts of Steps 2 and 3 will enable these figures to be reduced over time. Policy makers should note the difference between mean and marginal figures and avoid confusion in reporting frameworks. Marginal figures, which reflect the likely impacts of new output from commercial agriculture in the absence of safeguards, should be used to inform policy decisions but product reporting should use mean impacts to accurately describe the average impact of each unit of product.

Further work is required to improve understanding of the breakdown of LUC causal factors and to demonstrate how responsibility can be directly attributed.

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[1] The Mean is the emissions spread across total production of feedstocks, whereas the Marginal is the emissions spread across the increase in output.

1 Problems with current approaches to ILUC

Indirect Land Use Change (ILUC) has been raised as an important issue for biofuels. Recent models used to estimate ILUC and associated GHG emissions have been based on forward-casting the economic effects of marginal changes in the use or output of cropped materials[2]. These models are complex, with several degrees of freedom, inter-dependencies and feedback loops (Figure 1)[3].

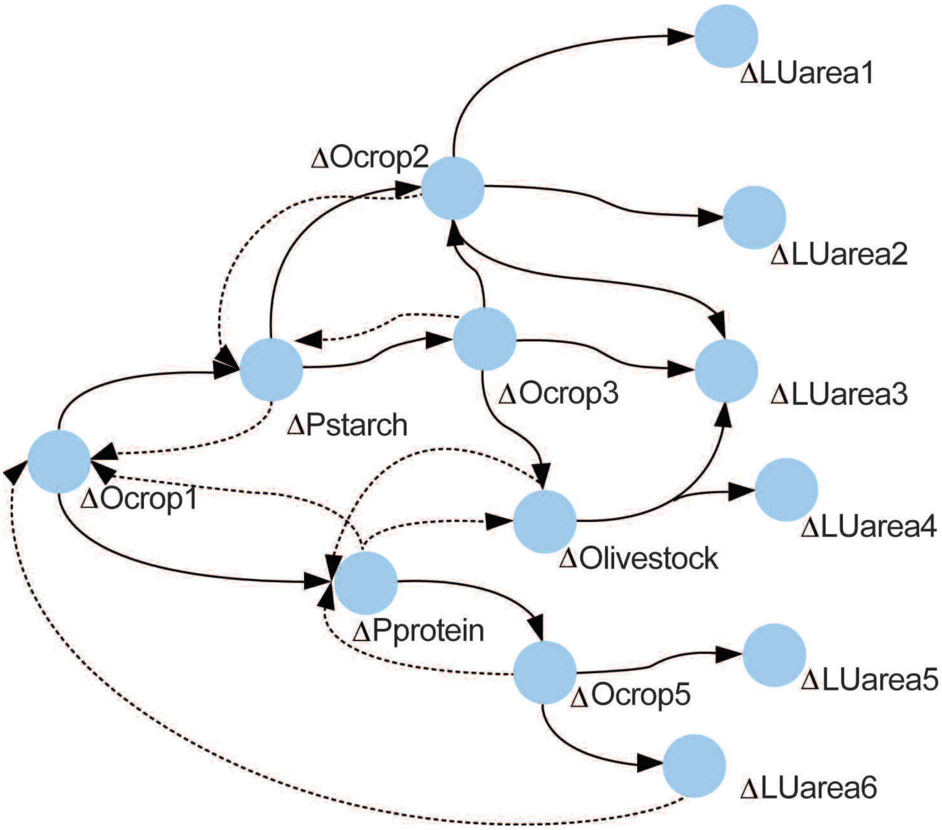

Figure 1
This flow diagram illustrates the steps and linkages involved in forward-casting the effect of a change in crop use or crop output upon land use change. A change in the use or output ("O") of crop 1 induces changes in the market prices ("P") for the crop itself and its co-products and therefore for the products which may substitute these. These price changes in turn stimulate changes in outputs of other crops, livestock and also consumption; then in response to these changes in prices producers in different parts of the world may react by making intensification and/or land use change ("LU") decisions. Because there are uncertainties at each step in the analysis the total uncertainties are multiplied. The effect of feedback loops (dashed lines) also increases total uncertainty. For example, more advanced models assume that changes in product prices have an effect on the rate of yield increases (intensification).

Box 1
Definition of ILUC: Land use change which occurs outside the production boundary of a feedstock, but which is caused by a change in the use or level of output of that feedstock.

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[2] Searchinger et al (2008); Ensus (2008).
[3] In statistics the term degrees of freedom is used to describe the number of values in the final calculation of a statistic that are free to vary.

Forward-casting models have several problems in terms of providing policy relevant information:

- Very high modelling uncertainty resulting from multiple degrees of freedom, feedback loops and complex interactions means that models conclusions are weakly supported by evidence and may have limited application.

- Models are not able to take account of real market conditions and discontinuities (models tend to assume prices and conditions of other products and processes are at equilibrium; whereas in reality there are multiple ILUC effects occurring at any time – Box 2).

- Models do not take account of multiple factors in land use change decisions (e.g. land tenure, land price speculation, market information, proximity of roads).

- Models are not based on actual land use change data and may either multiply (through double-counting) or under estimate actual emissions.

Box 2
Noise: any change in output or use of a crop (whether deliberate, or resulting from natural causes) will induce indirect effects.

For example:
- reductions in cereal output from Australia resulting from drought;
- increase meat production resulting from higher meat demand in China; and
- reduction in agricultural output as a result of removal of subsidies.

Given the interlinked nature of global agricultural markets it is virtually impossible to determine precisely where one indirect effect ends and another begins. Like ripples on a pond, indirect effects may be reinforced or dampened through interaction. The uncertainty associated with model outputs presents a barrier to international consensus on effective policies on ILUC since individual producer groups and countries tend to model from their own perspectives.

We note that recent studies have emphasised the indirect effects associated with biofuel policies. However, to provide comparability (and a full picture of indirect effects) it would be logical to subject all policies that might affect crop use or agricultural output to similar analysis. Thus, policies to promote agricultural set-aside or low intensity farming may reduce output from industrial countries (high output areas) may equally transfer production to developing countries.

Finally, the separation of attribution from management responsibility which arises from predictive modelling makes the formulation of effective LUC management strategies more difficult and may impede the development of local standards and controls. For example, if the responsibility for deforestation is attributed to remote actors then there will be less pressure on governments in areas where deforestation is occurring to control this process.

2 A Practical Approach Based on Allocation and Attribution of Responsibility

To address the problems of uncertainty, multiple-counting of emissions and remote attribution we propose a policy approach based on the following steps:

1. Estimation of LUC emissions associated with marginal changes in output based on a share of actual LUC emissions.
2. Separation of direct and indirect emissions.
3. Progressive attribution and acceptance of responsibility towards direct effects by each sector and producer.

Step 1. Estimation of LUC emissions based on a share of actual LUC emissions

As previously stated, one of the problems of forward-casting modelling is the potential to multiply (double-count, or count several times over) the total observed effect. To date, no ILUC models have referenced their output to the total effects associated with the increase in agricultural output.

When modelling complex systems (such as agricultural commodity markets coupled with land use decisions), it is essential to calibrate the model to the actual size of the problem (Box 3).

Box 3
This approach is consistent with the approach of both the UK government and the European Commission to better regulation, which inter-alia state that regulation should be proportionate.

We therefore treated the market as a “black box” and used standard allocation methods to apportion the total estimated LUC emissions to marginal production activities. We started with an estimate of total GHG emissions associated with LUC over the period 2000 – 2005, based on the FAO's estimate of 7.3 Mha forest lost per year during this period (FAO 2005) and IPCC factors for the carbon stock lost per unit of deforestation (IPCC 2000). Deforestation is the largest source of LUC emissions and further research is required to determine whether other LU-related emissions should be attributed to commercial agriculture[4]. We then used an FAO estimate[5] that 16% of total deforestation was attributable to commercial agriculture to derive a figure of 1,884 Mt CO_2 as an estimate of emissions attributable to the increase in commercial agricultural output from 2000 - 2005 (regardless of end market)[6]. Figure 2 provides an illustration of allocation of total LUC between different causal factors. Dividing the total emissions associated with the increase in commercial agriculture by the increase in production multiplied over 25 years provided a figure of 0.29 t CO_2 per tonne of increased production. To arrive at the LUC emissions associated with each biofuel type we then allocated the emissions between co-products of biofuel feedstocks on the basis of energy content[7] (the allocation to sugar cane and sugar beet was adjusted to take account of moisture content).

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[4] We understand that approximately 80% of GHG emissions associated with LUC are the result of deforestation. Other sources of LUC emissions include soil degradation, the burning of peat swamps and forest degradation. Further work is required to determine the extent to which these sources of emissions should be attributed to the expansion of commercial agriculture.

[5] FAO (1980) Global Forest Resources Assessment. We note that this FAO assessment pre-dates the period under consideration and further research is required to better understand the contribution of different sectors.

[6] In terms of LCA, we are effectively allocating the GHG emissions from LUC attributable to commercial agriculture on the basis of mass, and LUC is viewed as a multi-function process.

[7] We note that alternative methods of allocation could be considered, including mass and economic value.

Box 4

Marginal or Mean impact for product reporting?: Lifecycle assessments of marginal impacts (consequential LCAs) must be clearly differentiated from assessments of mean impacts (descriptive LCAs). It is important to note that previous estimates of ILUC have been based on marginal effects (ie – the effect of each additional unit of product), whereas the units used for reporting within the RTFO and RED are mean values (the average impact of a unit of product). Policy makers should be aware that while consequential LCAs are theoretically more representative of the impacts of new policies or incentives they are also subject to greater uncertainties. It should also be noted that it is mathematically incorrect to combine mean and marginal values.

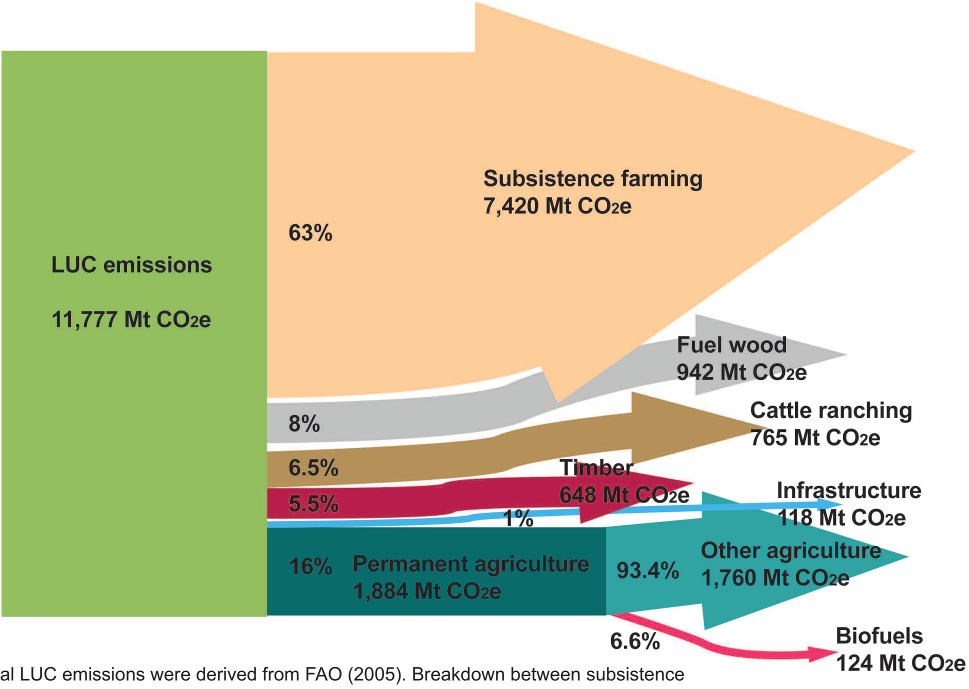
Using this process we derived marginal LUC emissions for various biofuels which ranged from 10 to 45 g CO_2 / MJ. Whereas mean LUC emissions[8] for various biofuels ranged from 0.9 to 4 g CO_2 / MJ (Box 4).

The full results of the calculations are shown in Table 1 (Appendix 1), and the marginal impacts are illustrated by flow diagrams in Figures 3 and 4 for bio-ethanol and bio-diesel crops.

A graph showing the addition of mean LUC factors to the RFA (2008) default factors is shown in Appendix 2.

Figure 2

Breakdown of global LUC emissions from 2000 to 2005 by major sector, according to the causal factors identified by FAO (1980)[9].



Total LUC emissions were derived from FAO (2005). Breakdown between subsistence farming, fuel wood, cattle ranching, timber and permament agriculture were taken from FAO (1980). The contribution of biofuels was based on the proportion of commercial agricultural output allocated to biofuels over the period 2000 - 2005.

The contribution of biofuels was based on the proportion of total feedstock used by this sector from 2000 to 2005. It was assumed that all biofuel feedstocks were produced by permanent agricultural systems. It is noted that the FAO breakdown pre-dates the period in question. Further research is required to better understand the differences and interactions between subsistence farming and commercial agriculture. For example, it may be possible for growth in commercial agriculture to reduce the LUC impacts of subsistence farming (through the production of cheaper food) on the other hand expansion of permanent agriculture may physically displace subsistence farmers to new lands.

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[8] The Mean is the emissions spread across total production of feedstocks, whereas the Marginal is the emissions spread across the increase in output.

[9] This was the best available evidence for breakdown of deforestation causes at the time of research. A more detailed review of recent literature is underway to improve this estimate.

In figures 3 & 4 (below) we allocate the marginal LUC emissions attributed to biofuels in figure 2 between biofuels and their co-products. Allocation was on the basis of energy content.

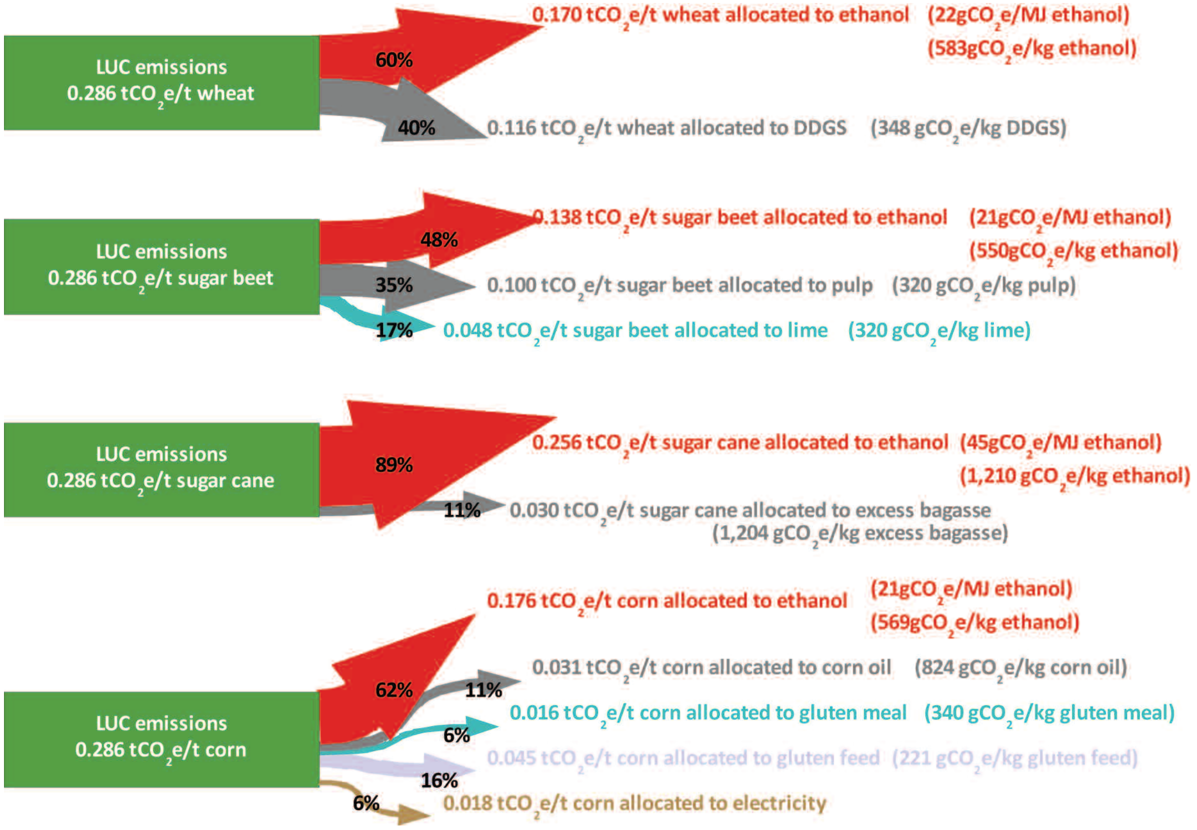

Figure 3
Breakdown of LUC emissions from 2000 to 2005 by the marginal increase in output of co-products for major bio-ethanol crops

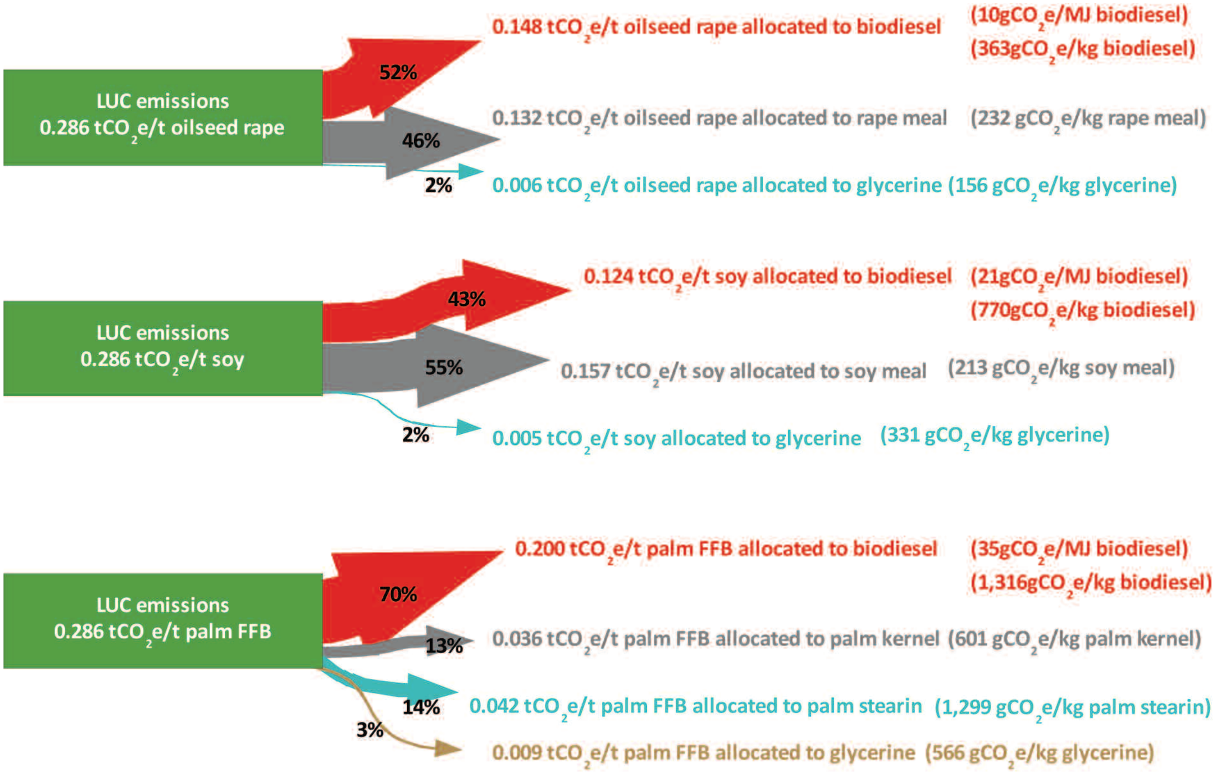

Figure 4
Breakdown of LUC emissions from 2000 to 2005 by the marginal increase in output of co-products for major bio-diesel crops

Step 2. Separation of Direct and Indirect Land Use Change Emissions

It is important to note that the LUC figures derived in Table 1 are estimates of Total LUC rather than the indirect effects. In order to preserve the proportionality of the overall problem (avoid multiple counting of emissions) and to work towards a way of defining management responsibility for indirect emissions we must separate direct and indirect effects, such that:

Total LUC Emissions = Direct LUC Emissions + Indirect LUC Emissions

Step 3. Progressive attribution and acceptance of responsibility towards direct effects

Emissions that are attributed to an industry sector as part of their direct responsibility and subject to a management plan – can be regarded as "direct" and thus no longer indirect.

Emissions that are taken on as direct fall out of the indirect pool and are no longer allocated across the market as a whole. For example, if users of palm oil for cosmetics define their areas of operations and accept responsibility for any emissions occurring within that area then they would be taken out of the general pool of emissions and not allocated indirectly to any other sector.

Over time the indirect portion of total LUC should fall through the following actions taken by the biofuel and other sectors:

- work within the sector and with other commercial agricultural sectors to define areas of responsibility and common standards (thus reducing indirect effects);
- where direct responsibility is assigned, work to reduce those emissions by ensuring that vegetation with high carbon density is conserved;
- producers of commercial crops for both biofuel and other purposes could even contribute to increasing the stocks of carbon on lands that had been degraded – for example logged forests not suitable for agriculture.

Following this approach the strategy for dealing with LUC associated with biofuels will fulfil the following requirements[10]:

- ***Transparent***: clear how responsibility is allocated between producers / products.
- ***Accountable***: each producer can be made accountable for a proportion of the LUC effect.
- ***Proportionate***: the scale of each contribution is proportional to output and the total corresponds to the magnitude of the overall problem.
- ***Consistent***: the rules of allocation are consistent across all crops and products regardless of end use.
- ***Targeted***: the approach encourages the industry to focus on actions that will result in conservation of terrestrial carbon stocks.

[9] These are BERR's requirements of good policy, and are also consistent with EU policy standards.

3 Conclusions and Recommendations

In the absence of a comprehensive and reliable model of global agricultural markets and land use decision making, forward-casting models represent a poor basis for quantifying ILUC associated with biofuels or other changes in agricultural output.

Remote attribution of responsibility for land use change also hinders practical measures to control and manage appropriate land use and agricultural development.

An approach based on the allocation of known LUC emissions to all marginal increases in output and the progressive attribution of direct responsibility to local actors provides a more practical basis for policy measures to control land use change and promote sustainability.

Further work will be required to determine the best methods of allocation and the share of total LUC emissions attributable to commercial agriculture. In particular, further work is required to determine the global contribution of commercial agriculture to land use change.

Descriptive GHG balances for biofuels (biofuel carbon intensity figures) should be based on mean GHG emissions per unit whereas policies to support particular fuels or technologies should consider marginal impacts, while noting that marginal impacts are likely to change over time and may be addressed through the measures described above.

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APPENDIX 1

Rough Estimate of LUC Emissions Attributable to increased Agricultural Output since 2000		
Based on the period 2000-2005		**Source**
Area of forest lost per year 2000-2005	7.3 Million ha	FAO 2005
Carbon lost per ha deforested	88 Tonnes C/ha deforested	IPCC - 1.5 GtC/17m ha
Emissions from deforestation	0.64 GtC per year	Derived from above
Emissions from deforestation over period (CO$_2$)	11,777 MtCO$_2$ over 5 years	Derived from above
Proportion of LUC emissions attributable to permanent agriculture	16%	FAO 1980
LUC emissions attributable to permanent (commercial)	1,884 MtCO$_2$	Derived from above
Increase in crop output between 2000 and 2005	263,353,660 tonnes	Derived from FAO 2008
Duration of additional crop output	25 years	Working assumption
Additional production over 25 years	6,584 Mt	Derived from above
Total CO$_2$ emissions per tonne of additional crop	**0.286 tCO$_2$e/t crop**	Derived from FAO 2008 and IPCC 2001

Ethanol from wheat		
Allocation of co-products by energy content:		
Proportion of wheat energy to bioethanol	60%	Derived from RFA
Proportion of wheat energy to DDGS	40%	Derived from RFA
Ethanol yield	0.29 t ethanol/t wheat	RFA 2007
DDGS yield	0.33 t DDGS/t wheat	Derived from RFA
Calorific value of bioethanol	26.8 MJ/kg	RFA 2007
LUC emissions from feedstock	**0.286 tCO$_2$e/t wheat**	**Derived from above**
LUC emissions allocated to ethanol	**0.170 tCO$_2$e/t wheat**	**Derived from above**
LUC emissions allocated to DDGS	**0.116 tCO$_2$e/t wheat**	**Derived from above**
LUC emissions allocated to ethanol	**0.583 tCO$_2$e/t ethanol**	**Derived from above**
LUC emissions allocated to DDGS	**0.348 tCO$_2$e/t DDGS**	**Derived from above**
LUC emissions allocated to wheat ethanol (marginal)	**22 gCO$_2$e/MJ ethanol**	**Derived from above**
LUC emissions from wheat ethanol (mean)	**1.9 gCO$_2$e/MJ ethanol**	**Derived from above**

Ethanol from sugar beet		
Allocation of co-products by energy content:		
Proportion of sugar beet energy to bioethanol	48%	Derived from RFA
Proportion of sugar beet energy to pulp	35%	Derived from RFA
Proportion of sugar beet energy to lime	17%	Derived from RFA
Ethanol yield	0.25 t ethanol/t sugar beet	RFA 2007
Pulp yield	0.31 t pulp/t sugar beet	Derived from RFA
Lime yield	0.15 t lime/t sugar beet	Dervied from RFA
Calorific value of biethanol	26.8 MJ/Kg	RFA 2007
LUC emissions from feedstock	**0.286 tCO$_2$e/t sugar beet**	**Derived from above**
LUC emissions allocated to ethanol	**0.138 tCO$_2$e/t sugar beet**	**Derived from above**
LUC emissions allocated to pulp	**0.100 tCO$_2$e/t sugar beet**	**Derived from above**
LUC emissions allocated to lime	**0.048 tCO$_2$e/t sugar beet**	**Derived from above**
LUC emissions allocated to ethanol	**0.550 tCO$_2$e/t ethanol**	**Derived from above**
LUC emissions allocated to pulp	**0.320 tCO$_2$e/t pulp**	**Derived from above**
LUC emissions allocated to lime	**0.320 tCO$_2$e/t lime**	**Derived from above**
LUC emissions allocated to sugar beet ethanol (marginal)	**21 gCO$_2$e/MJ ethanol**	**Derived from above**
LUC emissions from sugar beet ethanol (mean)	**1.8 gCO$_2$e/MJ ethanol**	**Derived from above**

Ethanol from corn		
Allocation of co-products by energy content:		
Proportion of corn energy to bioethanol	62%	Derived from RFA
Proportion of corn energy to corn oil	11%	Derived from RFA
Proportion of corn energy to gluten meal	6%	Derived from RFA
Proportion of corn energy to gluten feed	16%	Derived from RFA
Proportion of corn energy to electricity	6%	Derived from RFA
Ethanol yield	0.31 t ethanol /t corn	RFA 2007
Corn oil yield	0.04 t corn oil /t corn	Derived from RFA
Gluten meal yield	0.05 t gluten meal /t corn	Derived from RFA
Gluten feed yield	0.20 t gluten meal /t corn	Derived from RFA
Calorific value of bioethanol	26.8 MJ/Kg	RFA 2007
LUC emissions from feedstock	**0.286 tCO$_2$e/t corn**	**Derived from above**
LUC emissions allocated to ethanol	**0.176 tCO$_2$e/t corn**	**Derived from above**
LUC emissions allocated to corn oil	**0.031 tCO$_2$e/t corn**	**Derived from above**
LUC emissions allocated to gluten meal	**0.016 tCO$_2$e/t corn**	**Derived from above**
LUC emissions allocated to gluten feed	**0.045 tCO$_2$e/t corn**	**Derived from above**
LUC emissions allocated to electricity	**0.018 tCO$_2$e/t corn**	**Derived from above**
LUC emissions allocated to ethanol	**0.569 tCO$_2$e/t ethanol**	**Derived from above**
LUC emissions allocated to corn oil	**0.824 tCO$_2$e/t corn oil**	**Derived from above**
LUC emissions allocated to gluten meal	**0.340 tCO$_2$e/t gluten meal**	**Derived from above**
LUC emissions allocated to gluten feed	**0.221 tCO$_2$e/t gluten feed**	**Derived from above**
LUC emissions allocated to corn ethanol (marginal)	**21 gCO$_2$e/MJ ethanol**	**Derived from above**
LUC emissions from corn ethanol (mean)	**1.9 gCO$_2$e/MJ ethanol**	**Derived from above**

Ethanol from sugarcane		
Allocation of co-products by energy content:		
Proportion of sugarcane energy to bioethanol	89%	Derived from RFA
Proportion of sugarcane energy to excess bagasse	11%	Derived from RFA
Ethanol yield	0.2117 t ethanol/t sugarcane	RFA 2007
Excess bagasse yield	0.0250 t bagasse/t sugarcane	Dervied from RFA
Calorific value of bioethanol	26.8 MJ/kg	RFA 2007
LUC emissions from feedstock	**0.286 tCO$_2$e/t sugarcane**	**Derived from above**
LUC emissions allocated to ethanol	**0.256 tCO$_2$e/t sugarcane**	**Derived from above**
LUC emissions allocated to excess bagasse	**0.030 tCO$_2$e/t sugarcane**	**Derived from above**
LUC emissions allocated to ethanol	**1.210 tCO$_2$e/t ethanol**	**Derived from above**
LUC emissions allocated to excess bagasse	**1.204 tCO$_2$e/t excess bagasse**	**Derived from above**
LUC emissions allocated to sugarcane ethanol (marginal)	**45 gCO$_2$e/MJ ethanol**	**Derived from above**
LUC emissions from sugarcane ethanol (mean)	**4.0 gCO$_2$e/MJ ethanol**	**Derived from above**

Biodiesel from oilseed rape		
Allocation of co-products by energy content:		
Proportion of oilseed rape energy to biodiesel	52%	Derived from RFA
Proportion of oilseed rape energy to rape meal	46%	Derived from RFA
Proportion of oilseed rape energy to glycerine	2%	Derived from RFA
Proportion of oilseed rape energy to potassium sulphate	0%	Derived from RFA
Biodiesel yield	0.409 t biodiesel /t oilseed rape	Derived from RFA
Rape meal yield	0.568 t rape meal /t oilseed rape	Derived from RFA
Glycerine yield	0.041 t glycerine /t oilseed rape	Derived from RFA
Potassium sulphate yield	0.016 t pot. sulphate /t oilseed rape	Derived from RFA
Calorific value of biodiesel	37.2 MJ/Kg	RFA 2007
LUC emissions from feedstock	**0.286 tCO$_2$e/t oilseed rape**	**Derived from above**
LUC emissions allocated to biodiesel	**0.148 tCO$_2$e/t oilseed rape**	**Derived from above**
LUC emissions allocated to rape meal	**0.132 tCO$_2$e/t oilseed rape**	**Derived from above**
LUC emissions allocated to glycerine	**0.006 tCO$_2$e/t oilseed rape**	**Derived from above**
LUC emissions allocated to potassium sulphate	**0.000 tCO$_2$e/t oilseed rape**	**Derived from above**
LUC emissions allocated to biodiesel	**0.363 tCO$_2$e/t biodiesel**	**Derived from above**
LUC emissions allocated to rape meal	**0.232 tCO$_2$e/t rape meal**	**Derived from above**
LUC emissions allocated to glycerine	**0.156 tCO$_2$e/t glycerine**	**Derived from above**
LUC emissions allocated to potassium sulphate	**0.000 tCO$_2$e/t potassium sulphate**	**Derived from above**
LUC emissions allocated to oilseed rape biodiesel (marginal)	**9.75 gCO$_2$e/MJ biodiesel**	**Derived from above**
LUC emissions from oilseed rape biodiesel (mean)	**0.9 gCO$_2$e/MJ biodiesel**	**Derived from above**

Biodiesel from soy		
Allocation of co-products by energy content:		
Proportion of soy bean energy to biodiesel	43%	Derived from RFA
Proportion of soy bean energy to soy meal	55%	Derived from RFA
Proportion of soy bean energy to glycerine	2%	Derived from RFA
Proportion of soy bean energy to potassium sulphate	0%	Derived from RFA
Biodiesel yield	0.16 t biodiesel /t soy bean	Derived from RFA
Soy meal yield	0.73 t soy meal /t soy bean	Derived from RFA
Glycerine yield	0.02 t glycerine /t soy bean	Derived from RFA
Potassium sulphate yield	0.01 t pot. sulphate /t soy bean	Derived from RFA
Calorific value of biodiesel	37.2 MJ/Kg	RFA 2007
LUC emissions from feedstock	**0.286 tCO$_2$e/t soy**	**Derived from above**
LUC emissions allocated to biodiesel	**0.124 tCO$_2$e/t soy**	**Derived from above**
LUC emissions allocated to soy meal	**0.157 tCO$_2$e/t soy**	**Derived from above**
LUC emissions allocated to glycerine	**0.005 tCO$_2$e/t soy**	**Derived from above**
LUC emissions allocated to potassium sulphate	**0.000 tCO$_2$e/t soy**	**Derived from above**
LUC emissions allocated to biodiesel	**0.770 tCO$_2$e/t biodiesel**	**Derived from above**
LUC emissions allocated to soy meal	**0.213 tCO$_2$e/t soy meal**	**Derived from above**
LUC emissions allocated to glycerine	**0.331 tCO$_2$e/t glycerine**	**Derived from above**
LUC emissions allocated to potassium sulphate	**0.000 tCO$_2$e/t potassium sulphate**	**Derived from above**
LUC emissions allocated to soy bean biodiesel (marginal)	**20.69 gCO$_2$e/MJ biodiesel**	**Derived from above**
LUC emissions from soy bean biodiesel (mean)	**1.8 gCO$_2$e/MJ biodiesel**	**Derived from above**

Biodiesel from palm		
Allocation of co-products by energy content:		
Proportion of FFB energy to biodiesel	69.9%	Derived from RFA
Proportion of FFB energy to palm kernel	12.6%	Derived from RFA
Proportion of FFB energy to palm stearin	14.5%	Derived from RFA
Proportion of FFB energy to glycerine	3.01%	Derived from RFA
Proportion of corn energy to potassium sulphate	0%	Derived from RFA
Biodiesel yield	0.15 t biodiesel /t palm FFB	Derived from RFA
Palm kernel yield	0.06 t palm kernel /t palm FFB	Derived from RFA
Palm stearin yield	0.03 t palm stearin /t palm FFB	Derived from RFA
Glycerine yield	0.02 t glycerine /t palm FFB	Derived from RFA
Potassium sulphate yield	0.01 t pot. sulphate /t palm FFB	Derived from RFA
Calorific value of biodiesel	37.2 MJ/Kg	RFA 2007
LUC emissions from feedstock	**0.286 tCO$_2$e/t FFB**	**Derived from above**
LUC emissions allocated to biodiesel	**0.200 tCO$_2$e/t FFB**	**Derived from above**
LUC emissions allocated to palm kernel	**0.036 tCO$_2$e/t FFB**	**Derived from above**
LUC emissions allocated to palm stearin	**0.042 tCO$_2$e/t FFB**	**Derived from above**
LUC emissions allocated to glycerine	**0.009 tCO$_2$e/t FFB**	**Derived from above**
LUC emissions allocated to potassium sulphate	**0.000 tCO$_2$e/t FFB**	**Derived from above**
LUC emissions allocated to biodiesel	**1.316 tCO$_2$e/t biodiesel**	**Derived from above**
LUC emissions allocated to palm kernel	**0.601 tCO$_2$e/t palm kernel**	**Derived from above**
LUC emissions allocated to palm stearin	**1.299 tCO$_2$e/t palm stearin**	**Derived from above**
LUC emissions allocated to glycerine	**0.566 tCO$_2$e/t glycerine**	**Derived from above**
LUC emissions allocated to potassium sulphate	**0.000 tCO$_2$e/t potassium sulphate**	**Derived from above**
LUC emissions allocated to palm oil biodiesel (marginal)	**35 gCO$_2$e/MJ biodiesel**	**Derived from above**
LUC emissions from palm oil biodiesel (mean)	**3.1 gCO$_2$e/MJ biodiesel**	**Derived from above**

APPENDIX 2

Figure showing addition of mean LUC figures for biofuels to default RFA carbon intensity factors (RFA 2008).