For crops diverted from food to biofuel use, the emissions from the existing field are the same as in the baseline. The extra GHG emissions come from:

1. Intensification for higher yields
2. Annual emissions from farming newly-planted area
3. Emissions from indirect land use change

None of these is the “direct” annual emissions on the existing land
...but that’s all we know about!

The difference between 1, 2, 3 and the “direct” emissions is called “indirect” emissions.

1 is ignored ...(so far)
2 is assumed similar to the “direct’ emissions
ILUC models only consider “3”
Report “Biofuels: a New Methodology to Estimate GHG Emissions Due to Global Land Use Change”

published by the JRC’s
Institute for Environment and Sustainability
& Institute for Energy

at
http://re.jrc.ec.europa.eu/bf-tp/
### Source

<table>
<thead>
<tr>
<th>Source</th>
<th>Unit</th>
<th>Total emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annualized total GHG emissions from land use change (over a period of 20 years)</td>
<td>Mt CO$_2$eq</td>
<td>54.6</td>
</tr>
<tr>
<td>Extra Energy produced in 2020 (Scenario - Baseline)</td>
<td>MJ</td>
<td>865</td>
</tr>
<tr>
<td>Annual GHG emissions from land use change (over a period of 20 years)</td>
<td>g CO$_2$eq/MJ</td>
<td>63</td>
</tr>
</tbody>
</table>
Starts with ha per tonne biofuel in different world regions from different economic models

1. Assigns the extra area (PER REGION) on a map (spatially explicit to ~10km)
   …on the basis of
   - land suitability per crop (soil and climate)
   - distance from existing cultivation
     (method checked by back-casting in Brazil)

2. JRC LULUC and soil bureau experts give map of C released from soil and biomass on 10km grid
   (also N2O release is calculated: + 2-3%)

3. We sum all the emissions and divide by the extra biofuels to give gCO₂/tonne
by the team responsible for EU’s LULUC submission under Kyoto
<table>
<thead>
<tr>
<th>Emission Source</th>
<th>Method</th>
<th>Crop</th>
<th>Annual Emissions (g CO$_2$eq MJ$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual emissions from land use change (IFPRI BAU Scenario)</td>
<td>averaged over all crops</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Annual emissions from land use change (IFPRI FT Scenario)</td>
<td>averaged over all crops</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Annual emissions from land use change (IPTS)</td>
<td>averaged over all crops</td>
<td>63</td>
<td></td>
</tr>
</tbody>
</table>

method excludes expansion onto organic soils or peat

For comparison, IFPRI figure is 17 gCO2 / MJ

differences:  - fraction of forest vs. pasture (WINROCK for IFPRI)  
- carbon stocks figures
Indirect Land Use Change from increased biofuels demand:

Comparison of models and results for marginal biofuels production from different feedstocks

by Robert Edwards, Declan Mulligan and Luisa Marelli

ICCT ILUC meeting, Brussels, September 20, 2010
WHY MARGINAL SCENARIOS?

• If models are roughly linear for different shocks, they should be additive for:-
  • different biofuels
  • different crops and by-products
• Legislators need to understand how ILUC differs between biofuels from different feedstocks and regions
• If an ILUC factor is used, we need to know this quantitatively for all biofuels/feedstocks
• Anyway, to compare model results we at least need to compare the results per unit quantity of biofuel, vs. baseline
Most models are practically linear

PEMs: FAPRI-CARD, AGLINK-COSIMO, IMPACT, CAPRI

…….. linear by structure (in most situations).
GTAP-based models (GTAP, LEITAP…)

…linear for small shocks
…even for large shocks
...ILUC is probably not linear, but models generally are (or nearly so), because of lack of data for non-linearities. Linearity means marginal effects are additive for different feedstocks.
• JRC elicited estimates of marginal LUC ha per Mtoe of biodiesel and bioethanol in EU, US, (and Malaysia-Indonesia)
• All compared to the model’s existing baseline
• Models: FAPRI-CARD, IFPRI-IMPACT, LEITAP, AGLINK, GTAP-PURDUE and LCAssociates, CAPRI (EU-only)
• All models appear linear and additive even for shocks as large as the EU + US biofuels mandates
(except that in GTAP it rises moderately with increasing area)
The partial and full equilibrium models compared in this study are:

- FAPRI-CARD (from FAPRI-ISU)
- G-TAP (from Purdue University)
- IMPACT (from IFPRI)
- LEI-TAP (from LEI)
- AGLINK-COSIMO (from OECD) (comparative analysis not yet finished)
- CAPRI (from IPST) (EU only)

**IFPRI-MIRAGE (BAU and FT Scenario)**

### Marginal Scenarios

- A marginal extra ethanol demand in EU
- B marginal extra biodiesel demand in EU
- C marginal extra ethanol demand in US
- D marginal extra palm oil demand in EU (for biodiesel or pure plant oil use)

Other additional relevant scenarios (e.g. marginal extra ethanol from Brazilian sugar cane) could also be included.
We would like to thank in particular:

Martin Von Lampe (OECD),
Alla Golub (Purdue University)
Jacinto Fabiosa and Jerome Dumortier (FAPRI-CARD, Iowa State University)
Sonja Petersen and Bettina Kretschmer (Kiel Institute for the World Economy)
Ignacio Perez Dominguez and Geert Woltjer (Agricultural Economics Research Institute - LEI)
Elke Stefhest (PBL)
Simla Tokgoz and Siwa Msangi (International Food Policy Research Institute-IFPRI)
Stefan Unnasch (Life Cycle Associates)
Timothy Searchinger (Princeton University)
Michael O’Hare (University of California, Berkeley)
Peter Witzke (EuroCARE GmbH)
Steve Berry (Yale University)
All models show significant land use change

Marginal changes in area per Mtoe of biofuel

Biodiesel scenarios

Ethanol scenarios
All models show significant land use change.

Marginal changes in area per Mtoe of biofuel.
All models show significant land use change

- Marginal changes in area per Mtoe of biofuel
- Lowest ha/toe are from IFPRI
  - High % sugar cane
  - High yield elasticity
  - Area elasticity
  - Other reasons?

IFPRI-MIRAGE (DG TRADE) Average ha/toe biofuel

IFPRI-IMPACT
ROUGH ESTIMATE OF GHG Emissions due to ILUC by JRC-IE

<table>
<thead>
<tr>
<th>Scenario</th>
<th>gCO₂ per MJ of biofuels (spread over 20 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGLINK Sugar cane Eth Bra</td>
<td></td>
</tr>
<tr>
<td>IMPACT Coarse Grains Eth EU</td>
<td></td>
</tr>
<tr>
<td>IMPACT Maize Eth US</td>
<td></td>
</tr>
<tr>
<td>GTAP Coarse grains Eth US</td>
<td></td>
</tr>
<tr>
<td>AGLINK Coarse Grain Eth US</td>
<td></td>
</tr>
<tr>
<td>LEITAP Maize Eth US</td>
<td></td>
</tr>
<tr>
<td>IMPACT Wht Eth US</td>
<td></td>
</tr>
<tr>
<td>GTAP Wht Eth EU</td>
<td></td>
</tr>
<tr>
<td>IMPACT Wht Eth EU</td>
<td></td>
</tr>
<tr>
<td>AGLINK Wht Eth EU</td>
<td></td>
</tr>
<tr>
<td>FAPRI Wht Eth EU</td>
<td></td>
</tr>
<tr>
<td>LEITAP Wht Eth EU-Fra</td>
<td></td>
</tr>
<tr>
<td>GTAP Biod Ind/Mal</td>
<td></td>
</tr>
<tr>
<td>LEITAP Biod INDO</td>
<td></td>
</tr>
<tr>
<td>GTAP Biod mix EU</td>
<td></td>
</tr>
<tr>
<td>AGLINK Biod US</td>
<td></td>
</tr>
<tr>
<td>AGLINK Biod EU</td>
<td></td>
</tr>
<tr>
<td>FAPRI Biod EU</td>
<td></td>
</tr>
<tr>
<td>LEITAP Biod EU-Deu</td>
<td></td>
</tr>
</tbody>
</table>

Range is for the smallest and largest C emissions per ha from IPCC (excluding organic soils): 10-95 tC/ha.
Models reporting ILUC emissions vs. JRC-IE approximation

- GTAP Coarse grains Eth US
- GTAP Wht Eth EU
- GTAP Biod Ind/Mal
- GTAP Biod mix EU
- FAPRI Wht Eth EU
- FAPRI Biod EU
- IFPRI-MIRAGE Biofuels mix FT scenario
- IFPRI-MIRAGE Biofuels mix BAU scenario

- [Graph showing model results with error bars.]

- gCO₂ per MJ of biofuels (spread over 20 years)

- Something wrong with the error bars here.

- calculated from model
- JRC Estimation (40 tC/ha) with peat oxidation
Models reporting ILUC emissions vs. JRC-IE approximation

- GTAP Coarse grains Eth US
- GTAP Wht Eth EU
- GTAP Biod Ind/Mal
- GTAP Biod mix EU
- FAPRI Wht Eth EU
- FAPRI Biod EU
- IFPRI-MIRAGE Biofuels mix FT scenario
- IFPRI-MIRAGE Biofuels mix BAU scenario

- JRC Estimation (40 tC/ha) with peat oxidation
- calculated from model

Something wrong with the error bars here

FAPRI EU wheat “must be grown in EU”
- HIGHER animal feed cost
- EU meat replaced by ranching outside EU
  - marginal change assigned first to buffer farmland
  - small C loss assigned to buffer farmland
  - buffer is not replaced in the model

**gCO₂ per MJ of biofuels (spread over 20 years)**
PEAT OXIDATION: not included in the marginal models

Tropical Peat (forest) is not considered in land cover data used by ILUC models

Emissions from peat BURNING were overestimated after the Indonesian fires, but even without ANY burning, or effects off the plantation, the oxidation of peat gives significant emissions...

- at least 1/3 of new oil palm plantations on peat
- palm on peat means drainage; causes peat level to fall ~4cm/y
- ~57 tonnes CO$_2$/y per ha of drained peat @ 60% due to oxidation
- (new data on peat density implies it's double this)

Extra emissions from peat oxidation @ 19 tonnes CO2/ha/y of palm oil

<table>
<thead>
<tr>
<th>oil palm area change</th>
<th>kHa per Mtoe</th>
<th>tCO2/toe</th>
<th>gCO2/MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biodiesel scenarios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEITAP Biod EU-Deu</td>
<td>33</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>FAPRI Biod EU</td>
<td>51</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>AGLINK Biod EU</td>
<td></td>
<td>(still calculating)</td>
<td></td>
</tr>
<tr>
<td>AGLINK Biod US</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTAP Biod mix EU</td>
<td>16</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>LEITAP Biod INDO</td>
<td>561</td>
<td>11</td>
<td>252</td>
</tr>
<tr>
<td>GTAP Biod Ind/Mal</td>
<td>143</td>
<td>3</td>
<td>64</td>
</tr>
<tr>
<td><strong>Ethanol scenarios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEITAP Wht Eth EU-Fra</td>
<td>1.7</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>
The most important reasons why models differ in terms of ha/toe:

1. how much yields increase with price compared to area increasing with price (IFPRI has much higher ILUC savings from yield increases)

2. to what extent crop production is shifted to countries with lower yield

3. how by-products are counted (LEITAP has much lower ILUC savings from by-products)
Share of total LUC change within the region of the scenario and the Rest Of the World.

<table>
<thead>
<tr>
<th>Model</th>
<th>Scenario</th>
<th>% of total LUC change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Within scenario region</td>
</tr>
<tr>
<td>AGLINK-COSIMO</td>
<td>EU Biodiesel</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>EU Wheat Ethanol</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>US Biodiesel</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>US Maize Ethanol</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Brazil Sugar cane Ethanol</td>
<td>123%</td>
</tr>
<tr>
<td>CARD-FAPRI</td>
<td>EU wheat ethanol</td>
<td>103%</td>
</tr>
<tr>
<td></td>
<td>EU rapeseed biodiesel</td>
<td>8%</td>
</tr>
<tr>
<td>GTAP</td>
<td>EU Wheat Ethanol</td>
<td>44%</td>
</tr>
<tr>
<td></td>
<td>US Corn Ethanol</td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>EU Biodiesel (mix)</td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>Malay_Ind Biod</td>
<td>42%</td>
</tr>
<tr>
<td>IMPACT</td>
<td>EU Coarse grains</td>
<td>24%</td>
</tr>
<tr>
<td></td>
<td>EU Wheat</td>
<td>15%</td>
</tr>
<tr>
<td>LEITAP</td>
<td>US Maize Ethanol</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Wheat Ethanol Fra</td>
<td>55%</td>
</tr>
<tr>
<td></td>
<td>Biodiesel Deu</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>Biodiesel INDO</td>
<td>124%</td>
</tr>
</tbody>
</table>
DISCUSSION:

MARGINAL YIELD
FRONTIER YIELD
Going from tonnes to hectares

- Model output is change in tonnes of crop per country.
- How many ha of extra cropland?

- Most models calculate (extra hectares per crop)
  - \( = \frac{\text{extra tonnes}}{\text{yield of crop}} \)
  - …and then add the hectares.

- Example (next slide): how many ha for one extra Mtonne wheat, with all other crops constant
what do models do about marginal yield?

- Some models have yield of e.g. barley depending slightly on area of wheat.
- Some models include small factors (FAPRI 0.97) for marginal/average yield of the same crop in the same country.
- *Only GTAP* assumes constant yield-at-the-frontier independent of the crop displaced: 0.66 of the average yield for all crops in the region.
**Example** how many ha for one extra Mtonne wheat, …with all other crops constant?

For simplicity, this example only involves displacement of cereals.

For mixed oilseeds and cereals you need to convert first to tons of cereals-equivalent.

---

For clarity, this example only involves displacement of cereals. For mixed oilseeds and cereals you need to convert first to tons of cereals-equivalent.
Area of ILUC from extra EU-wheat demand: depends on **yield at the frontier of cultivation** whatever the crop which actually expands.

- **Yield increment**
- **wheat area increment**
- **barley area increment**
- **crop area increment**
- **soil C emissions**

**equivalent hectares at average EU wheat yield**

**hectares of ILUC at cereals frontier**
historical frontier/average yield for EU wheat

- ILUC depends on the ratio of the yield-of-crops-at-the- frontier to average-yield
- Depends on the size of the region you are considering
- Single cereals farm in EU: about 0.7
- Between farms at national scale: farm surveys show similar best/worst ratios of production cost
- weighted-average of (national cereals yields) weighted by (cropland reduction in the last 10 years):
  - (WA cereals yield)/EU wheat average 0.6
  - (WA rye yield)/EU wheat average 0.38
- For EU as a region you need to multiply the 3 factors
  - $0.7 \times 0.7 \times 0.38 = 0.19$, so ILUC could be 5 times higher!
- On the other hand, in Brazil new land “has ~ same yield”:
  - old-world (EU, India, China) vs. new world (Brazil, US)
DISCUSSION

YIELD INCREASES
Discussion from JRC workshop:

**Two yield-price effects:**

1. **Crop-price effect on yield**
   - = yield elasticity on price
   - short-term (1-5 years)
   - all models include it
   - but they don’t consider the extra emissions from extra inputs (much discussion)

2. **Crop-price effect on rate of yield improvement**
   (research spending effect)
   - biofuels mandates redirect research to increasing yields rather than reducing costs
   - so effect on farm emissions per tonne is not clear
   - 20 y time-lag before research results are seen in yields
1. Reversible effect of price on yield
   (yield elasticity on price)
   - yields from higher inputs
   - what is \( \frac{d(\text{emissions})}{d(\text{ton crop})} \)?

According to classical agro-economics,

\[
\frac{(\text{Nitrogen})}{(\text{ton crop})} = \frac{\text{price of crop}}{\text{price of nitrogen}}
\]

= 5 to 12 times the average nitrogen per tonne crop

BUT other inputs also increase yield with less emissions: this dilutes the marginal emissions per ton

...but for marginal emissions per ton to be less than average ones, i.e. \(< 1/5 \text{ to } 1/12\) of the extra spending would have to go on N. Seems unlikely, so marginal emissions are probably higher
Marginal fertilizer per marginal tonne of crop

• One CANNOT find this by naively correlating historical yield data against fertilizer because of collinearity (autocorrelation) problems;
  - it attributes yield gains due to time-learning to demand increase
  - SO IT GREATLY UNDERESTIMATES MARGINAL FERTILIZER USE
  - (real crop price generally DECREASES with time)
2. Irreversible effect of sustained higher crop price on rate-of-yield-increase, due to...

How big is this effect?

The driver for investment improving net return/ha is net-return/ha
The driver for higher yield is crop price

e.g. 10% sustained crop-price increase:
    say \(d(yield)/dt\) increases proportionally to price increase,
    from 1 to 1.1% per year (i.e. NO diminishing returns; instant effect),

    over 10 years yield goes up 11.6% instead of 10.4%:

    effective contribution to yield elasticity on price after 10 years is 0.12
    the effect can only be moderate
JRC-IE ANALYSIS
METHOD TO
COMPARE ILUC MODELS
The main effects in modelling LUC from biofuels

- Gross feedstock per toe of biofuel
- Mix of crops replacing feedstocks
- "Fraction saved by reduced food & feed consumption"
- Divide by
  - "Average world crop yield in baseline" (hectares per tonne)
  - Subtract
    - Area saved by "real" yield increase
  - Subtract
    - area 'saved' by 'increased' world average yield due to changes in crop mix and displacements of crops
  - Change in crop area
- Net Land use change (ha/toe)
- Change crop area
- By-products Credit
- "Fraction saved by reduced food & feed consumption"
- Divide by
  - "Average world crop yield in baseline" (hectares per tonne)
  - Subtract
    - Area saved by "real" yield increase
  - Subtract
    - area 'saved' by 'increased' world average yield due to changes in crop mix and displacements of crops
  - Change crop area
  - Mix of crops substituted by by-products

Area effect of byproducts
Simplified scheme used in this report:

Gross feedstock per toe of biofuel

- fraction saved by by-products
- fraction saved by reduced food & feed consumption

Divide by

average world crop yield in baseline

Subtract

area saved by “real” yield increase

Subtract

area ‘saved’ by ‘increased’ world average yield due to changes in crop mix and displacements of crops

= Crop area required (LUC)

TONNES

HECTARES

Includes price intensification and yield reduction on new areas

Includes change in world crop mix (cereals – oilseeds) and displacement of production between regions
### Example of model parameters (FAPRI-model)

<table>
<thead>
<tr>
<th>PER TOE BIOFUEL</th>
<th>EU Wheat Ethanol</th>
<th>EU Rapeseed Biodiesel</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Gross tonnes of feedstock</td>
<td>5.40</td>
<td>adjustment</td>
<td>3.0 adjustment</td>
</tr>
<tr>
<td>II. ...net of by-products (tonnes)</td>
<td>3.71</td>
<td>1.16</td>
<td>- 61% A (fraction of gross feedstock saved by by-products)</td>
</tr>
<tr>
<td>III. ...net of reduction in food use (tonnes)</td>
<td>2.45</td>
<td>0.03</td>
<td>- 97% B (fraction of net feedstock supplied by reduction in food use)</td>
</tr>
<tr>
<td>IV. corresponding hectares at average baseline</td>
<td>0.66</td>
<td>0.01</td>
<td>baseline production/baseline area (tonnes/ha)</td>
</tr>
<tr>
<td>V. baseline area from increased yield on baseline</td>
<td>0.59</td>
<td>-0.11</td>
<td>baseline area * (fractional yield increase (per region per crop) weighted by baseline area (per region per crop)) (ha/toe)</td>
</tr>
<tr>
<td>VI. ...minus the area 'saved' by 'increased'</td>
<td>0.39</td>
<td>0.40</td>
<td>fractional change in (total crops/total area) x baseline area (ha/toe)</td>
</tr>
</tbody>
</table>

**LUC (ha/toe)**
Feedstock per toe biofuel
   little variance between models

A Fraction of extra crops saved by by-products
   Modellers could generally only report directly the effect of by-products on the
demand of the principal feedstock.
   Does not include replacement of other crops by by-products.

B Fraction of extra crops (after correction for by-products) saved by reduced food consumption
   includes crops fed to animal for meat/dairy production

C Average Crop Yield
   This is only in the table for comparison

D Area saved by 'real' yield increase
   increase in average yield for all the crops in all regions, weighted by the baseline
   area-distribution of the crops

E Area saved by crop displacements
   Change in crop mix on existing land
   Area of a particular crop may diminish in one country and rise in another one
   which has a different yield
<table>
<thead>
<tr>
<th>Model and scenario</th>
<th>Feedstock (tonnes)</th>
<th>Feedstock adjustments (%)</th>
<th>Area without yield &quot;savings&quot; (ha)</th>
<th>Area adjustments (ha)</th>
<th>LUC (ha/toe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAPRI-CARD</td>
<td>EU Wheat Ethanol</td>
<td>5.4</td>
<td>- 31% - 34% + 3.7</td>
<td>0.66</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>EU Rapeseed Biodiesel</td>
<td>3.0</td>
<td>- 61% - 97% + 3.7</td>
<td>0.01</td>
<td>0.12</td>
</tr>
<tr>
<td>GTAP</td>
<td>EU Wheat Ethanol</td>
<td>5.2</td>
<td>- 32% - 46% + 5.5</td>
<td>0.34</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>US Coarse grains Ethanol</td>
<td>4.6</td>
<td>- 31% - 52% + 5.5</td>
<td>0.27</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>EU Biodiesel (mix)</td>
<td>2.4</td>
<td>- 52% - 1% + 5.5</td>
<td>0.21</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Malay_Ind Biodiesel</td>
<td>5.1</td>
<td>- 22% - 12% + 5.5</td>
<td>0.63</td>
<td>0.23</td>
</tr>
<tr>
<td>IMPACT</td>
<td>US Maize Ethanol</td>
<td>4.6</td>
<td>- 0% - 36% + 5.1</td>
<td>0.58</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>US Wheat Ethanol</td>
<td>4.9</td>
<td>- 0% - 47% + 5.1</td>
<td>0.51</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>EU Coarse grains Ethanol</td>
<td>4.8</td>
<td>- 0% - 11% + 5.1</td>
<td>0.83</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>EU Wheat Ethanol</td>
<td>4.9</td>
<td>- 0% - 47% + 5.1</td>
<td>0.51</td>
<td>0.54</td>
</tr>
<tr>
<td>LEITAP</td>
<td>Maize Ethanol US</td>
<td>5.0</td>
<td>- 7% - 4% + 4.2</td>
<td>1.07</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Wheat Ethanol Fra</td>
<td>5.5</td>
<td>- 1% - 3% + 4.2</td>
<td>1.26</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Biodiesel Deu</td>
<td>3.0</td>
<td>- 1% - 9% + 4.2</td>
<td>0.64</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>Malay_Ind Biodiesel</td>
<td>3.0</td>
<td>- 0% - 1% + 4.2</td>
<td>0.71</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Calculations:
- Feedstock (tonnes)
- fraction of gross feedstock saved by by-products (tonnes)
- fraction of net feedstock supplied by reduction in food use (tonnes)
- baseline production/baseline area (tonnes/ha)
- Would-be extra area without yield changes
- baseline area *average of fractional yield increase (per region per crop) weighted by baseline area (ha/toe)
- Area saved by total net yield effects - D (ha/toe)
- LUC ha/toe
The most important reasons why models differ in terms of ha/toe:

1. to what extent crop production is shifted to countries with lower yield
2. how much yields increase with price compared to area increasing with price (IFPRI has much higher ILUC savings from yield increases)
3. how by-products are counted (LEITAP has much lower ILUC savings from by-products)
<table>
<thead>
<tr>
<th>Emission Source</th>
<th>Method</th>
<th>Crop</th>
<th>Annual Emissions ( g \ CO_2eq \ MJ^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual emissions from land use change (IFPRI BAU Scenario)</td>
<td>averaged over all crops</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Annual emissions from land use change (IFPRI FT Scenario)</td>
<td>averaged over all crops</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Annual emissions from land use change (IPTS)</td>
<td>averaged over all crops</td>
<td>63</td>
<td></td>
</tr>
</tbody>
</table>

*method excludes expansion onto organic soils or peat*
THE END
<table>
<thead>
<tr>
<th>Emission Source</th>
<th>Method</th>
<th>Crop</th>
<th>Annual Emissions (g CO₂eq MJ⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td></td>
<td>41</td>
</tr>
<tr>
<td>Annual emissions from land use change (IPTS)</td>
<td>averaged over all crops</td>
<td></td>
<td>63</td>
</tr>
<tr>
<td>“Weighted values” for annual emissions from cultivation, processing, transport and distribution of the biofuel - IFPRI MIRAGE</td>
<td>“Default” RED methodology</td>
<td>BAU scenario</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>WTW methodology</td>
<td>FT scenario</td>
<td>27</td>
</tr>
<tr>
<td>Annual emissions from cultivation, processing, transport and distribution of the biofuel – JRC-IPTS AGLINK-COSIMO</td>
<td>“Default” RED methodology</td>
<td>BAU scenario</td>
<td>22</td>
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<tr>
<td></td>
<td>WTW methodology</td>
<td>FT scenario</td>
<td>17</td>
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<tr>
<td></td>
<td>RED methodology</td>
<td></td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>WTW methodology</td>
<td></td>
<td>42</td>
</tr>
<tr>
<td><strong>Fossil Fuel Comparator</strong></td>
<td>RED methodology</td>
<td></td>
<td>83.3</td>
</tr>
<tr>
<td></td>
<td>WTW methodology</td>
<td></td>
<td>87.0</td>
</tr>
</tbody>
</table>
## Annual GHG Emissions

Calculation of Annual GHG Emissions from Changes in Soil and Biomass Carbon Stocks per Amount of Energy Produced

<table>
<thead>
<tr>
<th>Source</th>
<th>Unit</th>
<th>IFPRI BAU</th>
<th>IFPRI FT</th>
<th>IPTS CG</th>
<th>IPTS GM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annualized total GHG emissions from land use change</td>
<td>Mt $CO_2$eq</td>
<td>10.1</td>
<td>12.4</td>
<td>54.6</td>
<td>55.7</td>
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<tr>
<td>(over a period of 20 years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extra Energy produced in 2020</td>
<td>MJ</td>
<td>300</td>
<td>303</td>
<td>865</td>
<td>865</td>
</tr>
<tr>
<td>(Scenario - Baseline)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extra Energy produced in 2020</td>
<td>Mtoe</td>
<td>7.2</td>
<td>7.3</td>
<td>20.6</td>
<td>20.6</td>
</tr>
<tr>
<td>(Scenario - Baseline)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Annual GHG emissions from land use change (over a period</td>
<td>g $CO_2$eq/MJ</td>
<td>34</td>
<td>41</td>
<td>63</td>
<td>64</td>
</tr>
<tr>
<td>of 20 years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual GHG emissions from land use change (over a period</td>
<td>t $CO_2$eq/toe</td>
<td>1.4</td>
<td>1.7</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>of 20 years)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Annual emissions per amount of energy produced are in the range of:

34-41 g $CO_2$eq MJ-1 for the IFPRI-MIRAGE scenarios and approx 63 g CO2eq MJ-1 for IPTS-AGLINK.