Quantifying the Climate Effects of Bioenergy: New Metrics

Annette Cowie, Miguel Brandão, Miko Kirschbaum and Task 38
Bioenergy – “carbon neutral”

(nearly)
Not carbon neutral because:

- Production chain emissions
- Non-CO₂ GHGs
- C stock change in biomass, soil (direct effect)
- C stock change in biomass or soil thru ILUC
- Albedo and other biophysical effects on climate
Global carbon pools

Atmosphere 760

Vegetation 560

Soil 2500
  • SOC 1550
  • SIC 950

Ocean 38400

Fossil fuel 4130

Units are Pg C ($10^{15}$g or Gt)

After Carlson et al 2001; data from Lal, 2008
Task 38 Standard Methodology

- Compare project with reference energy, land use
- Consider whole system life cycle
  - Production chain, end of life
- System boundary
  - Deliver equivalent service
- Scope:
  - All greenhouse gases CO₂ and non-CO₂
  - C stock change in biomass, soil, ILUC, albedo
- Emissions reduction per unit biomass/land
- Result is specific to each situation
Bioenergy

- Carbon neutral?
  - Maybe nearly

- Climate neutral?
  - Not if you start with existing forest

F Cherubini NTNU
The cause-effect chain

GHG Emissions / Removals
(CO₂, CH₄, N₂O, HFC, PFC, NOₓ, SO₂, …)

Atmospheric Concentrations
(CO₂ppmv)

Radiative Forcing
(W m⁻²)

Climate Change
(Δ temperature, precipitation, sea level, …)

Impacts
(natural resources, ecosystems, human health)
Atmospheric [CO2] - pulse emission

\[ GWP_i = \frac{\int_{TR}^{TH} a_i c_i(t) dt}{\int_{TR}^{TH} a_{CO_2} c_{CO_2}(t) dt} \]

- **CH4**
- **CO2**
Lashof approach

\[ y(t) = A_0 + \sum_{i=1}^{i=3} A_i e^{\left(\frac{t}{\tau_i}\right)} \]

\[ f_{IRF}(t, r = 100) \]

\[ f_{CBC}(t, r = 100) \]
\[
GWP_{\text{bio}} = \frac{AGWP_{\text{bio}CO_2}}{AGWP_{CO_2}} = \frac{C_0 \int_0^{TH} \alpha_{CO_2} \cdot f(t) \, dt}{C_0 \int_0^{TH} \alpha_{CO_2} \cdot y(t) \, dt}
\]

\(GWP_{100} = 0.73\)
<table>
<thead>
<tr>
<th>r</th>
<th>$GWP_{bio}$ (TH = 100)</th>
<th>$GWP_{bio}$ (TH = 500)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>0.003</td>
</tr>
<tr>
<td>8</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>10</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>20</td>
<td>0.08</td>
<td>0.02</td>
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<td>30</td>
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<td>0.30</td>
<td>0.05</td>
</tr>
<tr>
<td>80</td>
<td>0.34</td>
<td>0.06</td>
</tr>
<tr>
<td>90</td>
<td>0.39</td>
<td>0.07</td>
</tr>
<tr>
<td>100</td>
<td>0.43</td>
<td>0.08</td>
</tr>
</tbody>
</table>

**Labels:**
- Annual crops
- Fast growing biomass
- Tropical forest
- Temperate forest
- Boreal forest
The cause-effect chain

GHG Emissions / Removals
(CO₂, CH₄, N₂O, HFC, PFC, NOₓ, SO₂, …)

Atmospheric Concentrations
(CO₂ppmv)

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Climate Change
(Δ temperature, precipitation, sea level, …)

Impacts
(natural resources, ecosystems, human health)
Global Temperature Change Potential GTP

\[ GTP_i(t) = \frac{AGTP_i(t)}{AGTP_{CO_2}(t)} = \frac{\Delta T_i(t)}{\Delta T_{CO_2}(t)} \]

blue – CO2, green and red – gases with lifetime of 1, 5 and 13 years respectively
Example 1: Mature forest converted to bioenergy plantation (large carbon debt)

Brandão, Kirschbaum, et al. in preparation
Calculate Bioenergy Factors

\[ B_e = 1 - \frac{C_b}{C_f} \]

\( C_b \): the biospheric carbon debt

\( C_f \): the fossil-fuel carbon saving

All integrated over 100 years

<table>
<thead>
<tr>
<th>( B_e )</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1</td>
<td>Biospheric C-stock changes add to benefit</td>
</tr>
<tr>
<td>= 1</td>
<td>Bioenergy is carbon neutral</td>
</tr>
<tr>
<td>1 &gt; ( B_e &gt; 0 )</td>
<td>Bioenergy is not carbon neutral, but better than fossil fuels</td>
</tr>
<tr>
<td>&lt; 0</td>
<td>Bioenergy is worse than fossil-fuel use (i.e. carbon stock loss is greater than benefit from fossil-fuel substitution)</td>
</tr>
</tbody>
</table>

Brandão, Kirschbaum, et al. in preparation
$B_e > 1$: Very good
$B_e = 1$: Carbon neutral
$1 > B_e > 0$: Not carbon neutral, but better than fossil fuels
$B_e < 0$: Worse than fossil-fuels

Brandão, Kirschbaum, et al. in preparation
Example 2: Converting a non-productive grassland to bioenergy plantation (carbon bonus – no debt)

Brandão, Kirschbaum, et al. in preparation

(b) Forest on pasture

Göran
Forest on grassland

\[
\begin{align*}
B_e & > 1: \quad \text{Very good} \\
B_e & = 1: \quad \text{Carbon neutral} \\
1 & > B_e > 0: \quad \text{Not carbon neutral, but better than fossil fuels} \\
B_e & < 0: \quad \text{Worse than fossil-fuels}
\end{align*}
\]

Brandão, Kirschbaum, et al. in preparation
Example 3: Converting non-productive grassland to bioenergy crop (trivial C storage changes)

Brandão, Kirschbaum, et al. in preparation
Energy crop on grassland

\[ B_e > 1: \] Very good  
\[ B_e = 1: \] Carbon neutral  
\[ 1 > B_e > 0: \] Not carbon neutral, but better than fossil fuels  
\[ B_e < 0: \] Worse than fossil-fuels

Brandão, Kirschbaum, et al. in preparation
Preliminary conclusions re metrics

- Conventional LCA ignores timing of emissions and removals
- There is no consensus on methods to quantify timing effects
- ISO/TS 14067 specifies that LCI must include timing
- Metrics for climate impact assessment give widely divergent results, depending on time frame of assessment, short vs long term focus
- There is no one metric that gives the complete picture – it can be instructive to apply several metrics.
Spatial scale?
Figure 1a  Single stand

C stock

Blue: Reference, harvested for timber only

Average C stock blue stand

ΔC: Additional biomass (residues) harvested for bioenergy. Decays on site in reference case.

GHG cost

Average C stock red stand

Red: harvested for timber + bioenergy. C stock reduced throughout the rotation compared with blue stand.

T0  T1  T2  T3

Time
**Figure 1a  Single stand**

Blue: Reference, harvested for timber only

ΔC: Additional biomass (residues) harvested for bioenergy. Decays on site in reference case.

Average C stock blue stand

GHG cost

Average C stock red stand

Red: harvested for timber + bioenergy. C stock reduced throughout the rotation compared with blue stand

**Landscape scale: Carbon stocks stable**

ΔC

GHG cost (red of blue)
Above-ground C stock (t)

Year

Δ C stock
**Single stand**

- **C stock**
  - Blue: Reference, harvested for timber only
  - Average C stock blue stand

  ![Graph of C stock over time with reference to timber harvest and green management](image)

- **GHG cost**
  - Average C stock green stand
  - Average C stock red stand
  - Red: harvested for timber + bioenergy, C stock reduced throughout the rotation compared with blue stand

**Landscape scale: Carbon stocks stable**

- **C stock**
  - Purple: Enhanced forest management outweighs the effect of increased biomass removal

  ![Graph of C stock over time with reference to enhanced forest management](image)

- **GHG cost (red of blue)**

**Landscape scale: Carbon stocks increasing**

- **C stock**
  - Enhanced C sequestration
  - Foregone C sequestration

  ![Graph of C stock over time with reference to enhanced C sequestration](image)
Carbon stock and harvest in Swedish forests have both grown over last century
On the Timing of Greenhouse Gas Mitigation Benefits of Forest-Based Bioenergy

This statement was prepared by
Professor Annette Cowie, University of New England, Australia; Associate Professor Göran Berndes, Chalmers University of Technology, Sweden; Professor Tat Smith, University of Toronto, Canada; and others from other members of Tasks 38, 40 and 43. The statement addresses a much debated issue – the timing of greenhouse gas emissions and carbon sequestration when biomass from existing managed forests is used for energy vs displacement of fossil fuels. The purpose of the statement, which is aimed at policy advisors and policy makers, is to explain the essence of this debate and so propose a perspective that considers the broader context of forest management and the role of bioenergy in climate change mitigation.

IEA Bioenergy
IEA Bioenergy: EdGen0004

Timing statement
published July 2013
ieabioenergy.com/
iea-publications/

Annette Cowie,
Göran Berndes,
Tat Smith
and others from
Tasks 38, 40 and 43
IEA Bioenergy Statement:

- Policymakers need to consider the big picture - the whole life cycle, the long term, human influences
- Biomass for energy is usually one of several products from a managed forest
- Forest C stocks fluctuate (at the stand level) over time and space - a forest is a mosaic of age classes
- Forest C stock should be considered across the estate
  - A function of management and natural factors
  - May be increasing or decreasing or stable
IEA Bioenergy Statement:

- If C stock decreases (relative to “without bioenergy” scenario), this is an emission that must be compensated through avoiding fossil fuels, before bioenergy gives net mitigation benefit.
- Loss in C stock can be minimised by investment in intensive forest management.
IEA Bioenergy Statement:

- Bioenergy benefits increase in long term
- GHG cost of forest bioenergy is an investment in establishing renewable energy system
Case Study – South Coast NSW

Ximenes et al. (2012) Forests
To meet global temperature targets, scientists have estimated a concentration of atmospheric GHGs that should not be exceeded. The difference between current concentrations and this threshold represents the atmospheric capacity for GHG emissions – the “emissions space.”

Critical strategic question: how should society use the remaining emissions space?
Development of new energy and transport systems will take time, and will create GHG emissions
• Some of the emission space could be used to develop a bioenergy industry to provide renewable and climate friendly energy services for the world.

Remaining emission space

Fill it up with fossil carbon

...or use some space for developing alternatives to fossil fuels?

LUC for bioenergy

Non-fossil fuel related

Non-fossil fuel related
Global carbon pools

Units are Pg C ($10^{15}$ g or Gt)

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After Carlson et al. 2001; data from Lal, 2008
Climate Change Effects of Biomass and Bioenergy Systems

www.ieabioenergy-task38.org

annette.cowie@dpi.nsw.gov.au

Timing statement:

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