Projections of environmental impacts of biofuels across scenarios using prospective LCA

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OR2022
8th September 2022

IEA Bioenergy Task 45
https://task45.ieabioenergy.com/
Integrated Assessment Models (IAMs) assess the interactions between human and natural systems.

They contain stylized representations of:
- Energy system
- Agricultural economy
- Climate
- Land system

They bridge the Science/Policy interface:
- Scenario Analysis: What if?
- What are the drivers or constraints of change?
- How do technology and policy choices lead to different outcomes?
- Uncertainties? Sensitivities?

Environmental impacts of biofuels using prospective LCA
Their focus area has been studying climate change mitigation strategies
- Working Group III of the Intergovernmental Panel on Climate Change (IPCC)
- Amongst others, they have highlighted the importance of biofuels
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**Share of biofuels in Transport final energy**
*Colours represent increasing climate targets*

![Graph showing the share of biofuels in transport final energy over time.](IPCC_AR6_WGIII_SPM_2022)

**Context**

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IPCC, AR6 WGIII, SPM (2022)
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Increasingly, *Sustainable Development Goals* are becoming an important guiding principle
- But the SDGs cover a huge landscape, which IAMs do not yet cover
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In order to better understand the broader implications of decarbonization strategies, need to look beyond mitigation potential

→ *Investigate broader environmental impacts of different strategies*
## Linking IAMs and LCA

### Different scopes of methods

<table>
<thead>
<tr>
<th>Integrated Assessment Models</th>
<th>Life Cycle Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward looking</td>
<td>Single timestep</td>
</tr>
<tr>
<td>Projects system dynamics</td>
<td>Snapshot of system (energy, land, etc.)</td>
</tr>
<tr>
<td>Aggregate</td>
<td>High detail</td>
</tr>
<tr>
<td>Focus on costs &amp; emissions</td>
<td>Multiple impact categories</td>
</tr>
</tbody>
</table>

![Graph showing environmental impacts of biofuels using prospective LCA](image)
Linking IAMs and LCA

- Different scopes of methods

*Research Aim: Use IAM projections to make prospective LCA consistent with system-wide changes – focusing on the case of biofuels.*
Linking IAMs and LCA

- **premise**: open-source tool that integrates IAM scenarios into Life Cycle Inventory databases

- IAMs scenarios used as input into the LCI database (e.g., ecoinvent)

- Transform LCI database, to represent the future background system (transport, industry, electricity, land use, etc.), at different timesteps

- Export database into common LCA software

- Steps 4 & 5 would return LCA indicators back into IAM decision process (work in progress).

Sacchi et al. (2022)
Method

› Use the **IMAGE** Integrated assessment model
  - Developed and maintained by the *PBL Netherlands Environmental Assessment Agency*
  - [www.pbl.nl/IMAGE](http://www.pbl.nl/IMAGE)

› Scenarios
  - Shared Socioeconomic Pathway 2 (SSP2) – middle of the road socioeconomic and technological developments
  - *Baseline, RCP2.6* (∼2°C), *RCP1.9* (∼1.5°C)

› Model results used to transform LCI database
  - Transport & industrial energy use
  - Power system
  - Land use and agricultural system
  - 26 regions
Method

LCA

1. CO₂ emissions from agricultural activities.
2. Transportation of agricultural products.
3. CO₂ emissions from manufacturing processes.
5. Land use change.
6. Consumption and use phase.
7. Final disposal and recycling.
Method

LCA

IAM
Method

- Investigate environmental impacts of bioethanol and biodiesel routes...
  - Maize
  - Sugarcane
  - Palm oil
  - Miscanthus
  - Poplar
  - Switchgrass
  - With and without Carbon Capture and Storage

- ... and how these impacts change with evolving energy and land systems
  - Across geographies, scenarios and time
  - Across different environmental indicators
Selected Results

GWP$_{100}$ | Functional Unit: 1 MJ of crop

- **Miscanthus**
  - Land use
  - energy (fuel, elec.)
  - pesticide
  - transport
  - N2O
  - fertilizer
  - seed
  - various additives
  - direct emissions
  - operation

- **Sugarcane**
  - Land use
  - energy (fuel, elec.)
  - machinery
  - transport
  - N2O
  - fertilizer
  - seed
  - pesticide
  - various additives
  - direct emissions
  - infrastructure

- **South Africa**
- **Indonesia**
- **Brazil**

- **+3.5C**
- **+2C**
- **+1.5C**

Environmental impacts of biofuels using prospective LCA

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Selected Results

Environmental impacts of biofuels using prospective LCA

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GWP\textsubscript{100} | Functional Unit: 1 MJ of ethanol

Miscanthus

Sugarcane

- Fossil gasoline (incl. combustion)
- Energy (fuel, elec.)
- Various additives
- Biomass input
- Infrastructure

+3.5°C

+2°C

+1.5°C
Selected Results

GWP$_{100}$ | Functional Unit: 1 MJ of ethanol with CCS

<table>
<thead>
<tr>
<th>Miscanthus (w. CCS)</th>
<th>Sugarcane (w. CCS)</th>
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<tr>
<td>+3.5C</td>
<td></td>
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Environmental impacts of biofuels using prospective LCA

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Selected Results

Functional Unit: 1 MJ of ethanol, 2010 = 1

- **Eucalyptus, Brazil**
- **Miscanthus, South Africa**
- **Palm oil, Indonesia**

Environmental impacts of biofuels using prospective LCA
Brazil, 2050, +3.5C

Selected Results

Functional Unit: 1 MJ of ethanol

- GWP 100a
- Agricultural land occupation
- Fossil depletion
- Freshwater ecotoxicity
- Freshwater eutrophication
- Human toxicity
- Ionising radiation
- Marine ecotoxicity

Categories:
- Biomass input
- Energy (fuel, elec.)
- Fermentation CO2
- Infrastructure
- Transport
- Various additives
Further work

- Incorporate back into IAM scenario analysis
  - Project pathways based on multiple environmental indicators (*not just CO₂ mitigation*)
  - Need to develop an appropriate *Environmental Impact* indicator
    - How to weigh different impacts?

Sacchi et al. (2022)
Incorporate back into IAM scenario analysis

- Project pathways based on multiple environmental indicators (*not just CO₂ mitigation*)
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Broaden analysis to other technologies

- Improve understanding of environmental implications of system change
- *Biofuels vs. fossil fuels vs. e-fuels*

Repeat analysis with other IAMs and broader scenario set

- Results depend on the projections of the IMAGE model.
  - Other models may show very different pathways
  - Standardized setup of the *premise* tool allows for study to be repeated with off-the-shelf results
- Investigate the effect of alternative scenario narratives (Green-growth, regionalization, post-growth, etc.)
Conclusions

› Environmental impact of biofuels not static
  – Varies across time, region, scenario
  – Need to account for these changes when developing strategies aiming to meet multiple goals

› Different biofuels types, different impacts
  – Advanced biofuels (miscanthus, poplar, switchgrass) have impacts from required additives (enzymes, acids, etc.)
  – Different crop productivities lead to different impacts related to land-use
  – Impacts may be further reduced with novel farming techniques reducing the need for land, fertilizers, and energy use (no-till, selection of high yielding species, selective fertilizing, etc.)

› Synergies between climate and environmental targets
  – Movement of energy system towards renewables reduces some of the impacts of biofuel production, but mostly when CCS is considered.
Thanks!

More information:

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