IEA Bioenergy
Technology Collaboration Programme

Quantifying the climate change effects of bioenergy and BECCS

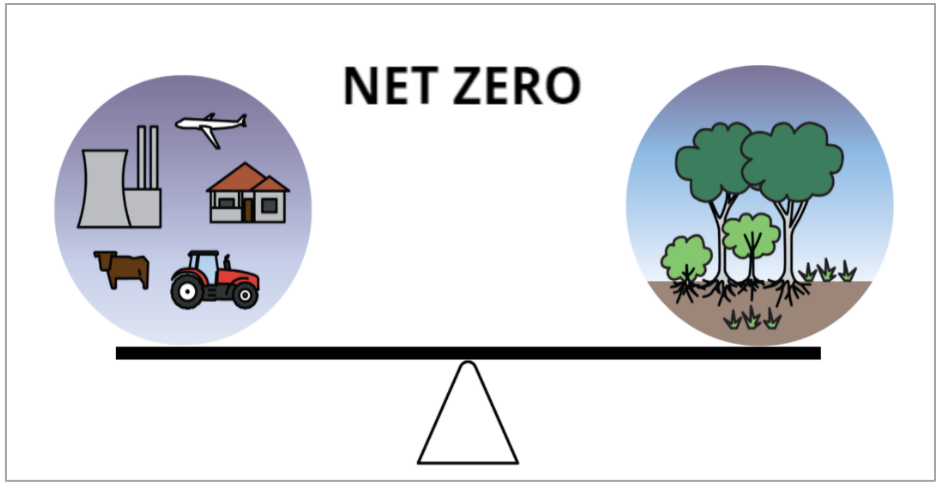
Annette Cowie
NSW Department of Primary Industries and Regional Development

Members of IEA Bioenergy Task 45
“Climate and sustainability effects of bioenergy within the broader bioeconomy”

Technology Collaboration Programme
by iea

UNFCCC: The Paris Agreement

- Aim: limit temperature rise to well below 2°C, preferably 1.5 °C
- Emissions to be balanced by removals in 2nd half of century
  - – net zero emissions



Bioenergy – energy from biomass

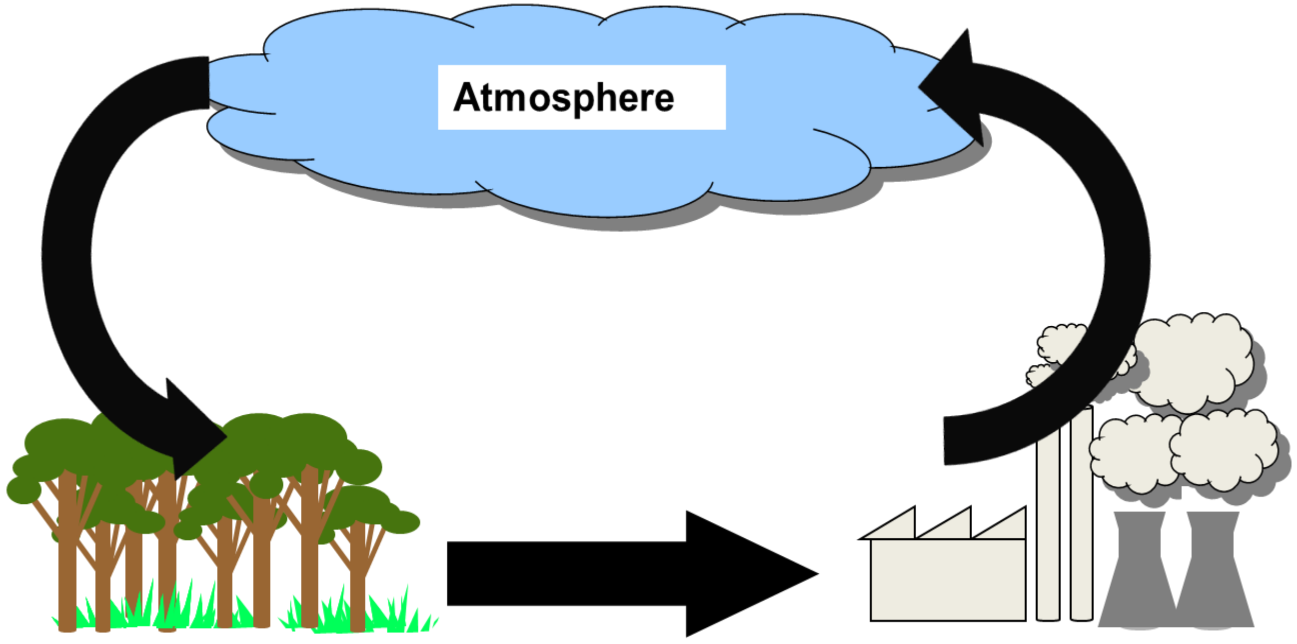
- Biomass is organic material e.g. plants, animals, manure – not fossilised
- Biomass contains carbon from the atmosphere and stored energy from the sun
- Biomass is a renewable resource if it is regrown after harvest

Photosynthesis

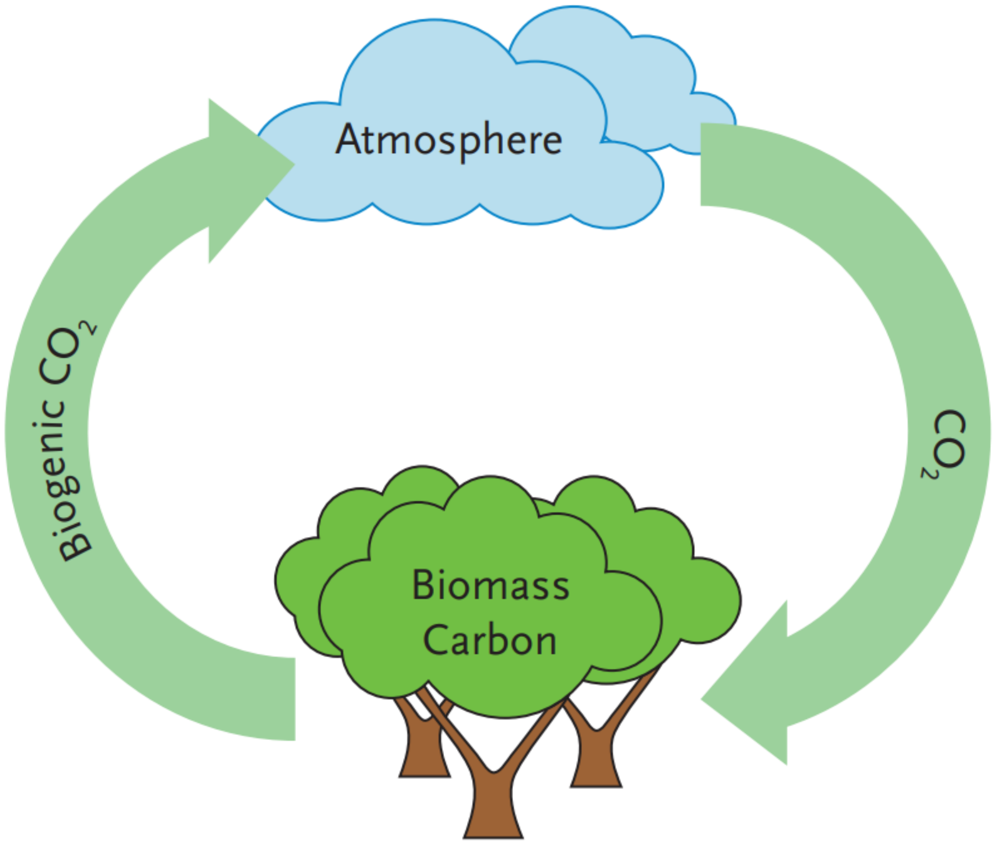
Through photosynthesis, plants convert the sun's energy into sugars

(water)		(carbon dioxide)		(sunlight)		(glucose)		(oxygen)
$6\,H_2O$	+	$6\,CO_2$	+	radiant energy	→	$C_6H_{12}O_6$	+	$6\,O_2$

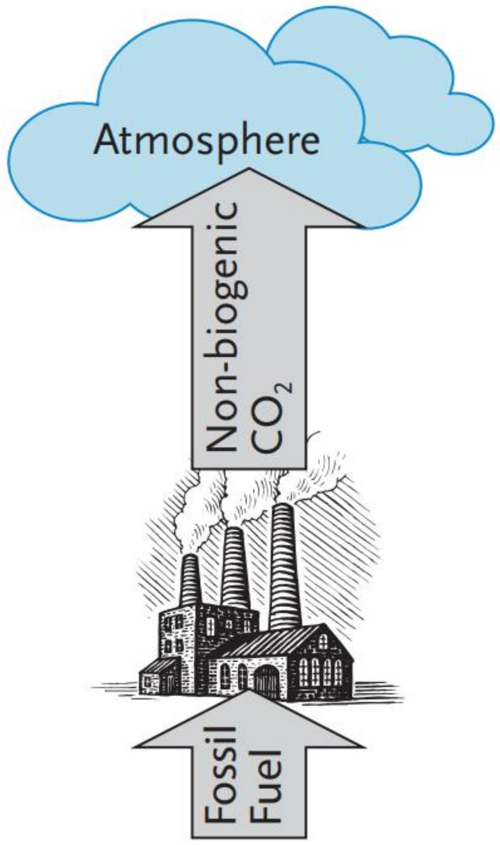
Bioenergy carbon cycle



Bioenergy vs fossil fuel

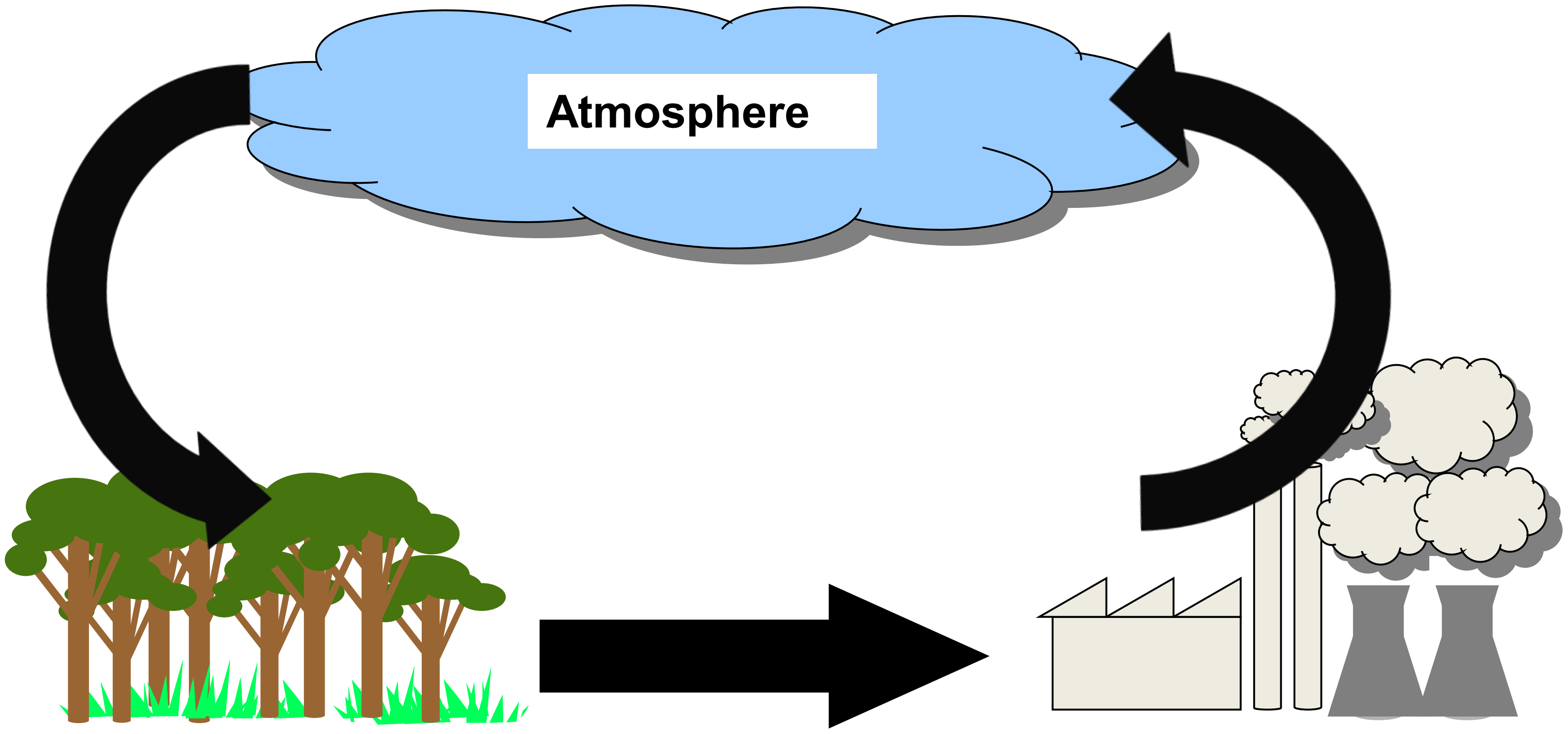


Circular C flow

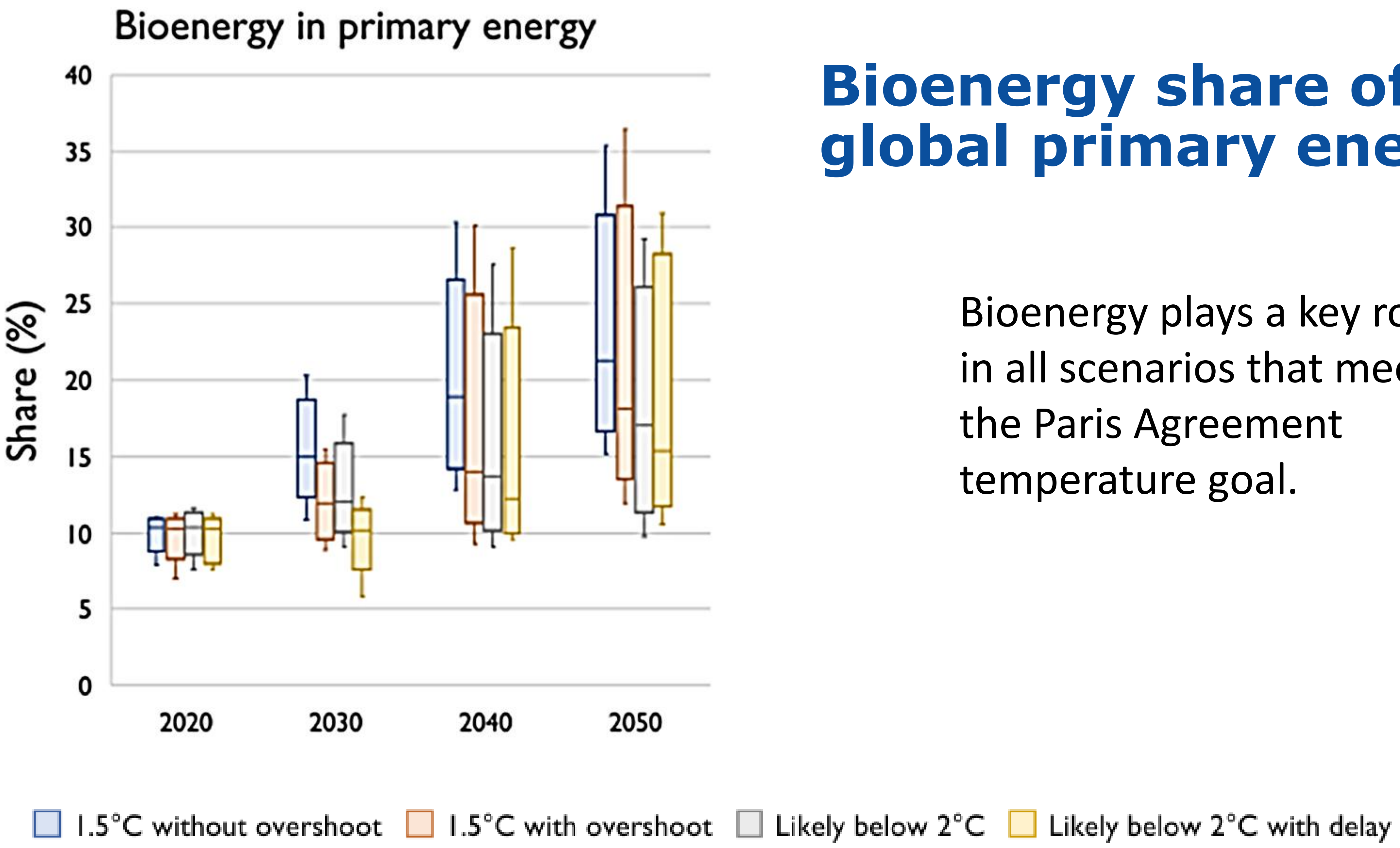


Linear C flow

Bioenergy – “carbon neutral” (almost)

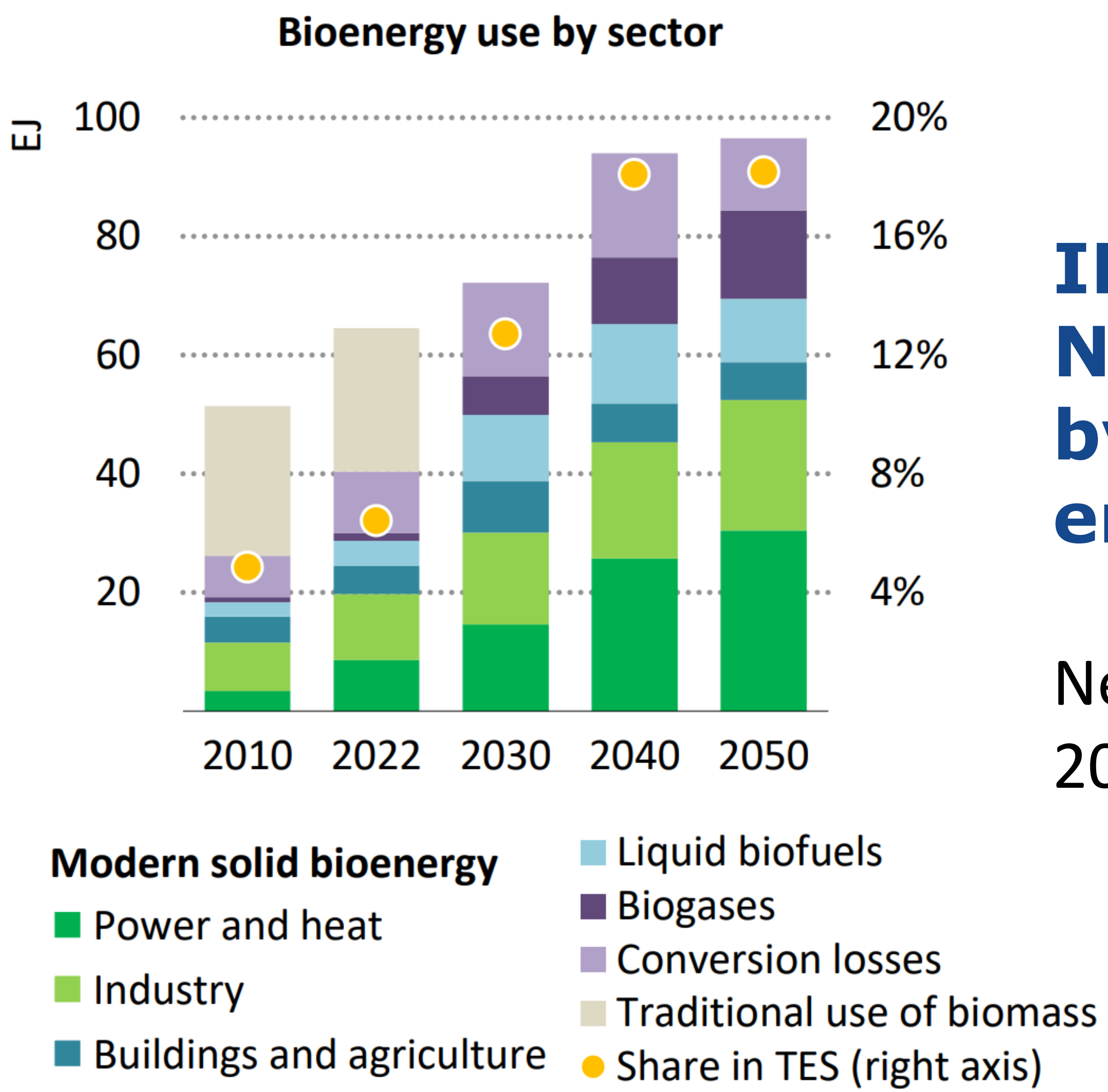


Bioenergy share of global primary energy



Bioenergy plays a key role in all scenarios that meet the Paris Agreement temperature goal.

IPCC AR6 WGIII FIGURE 6.30

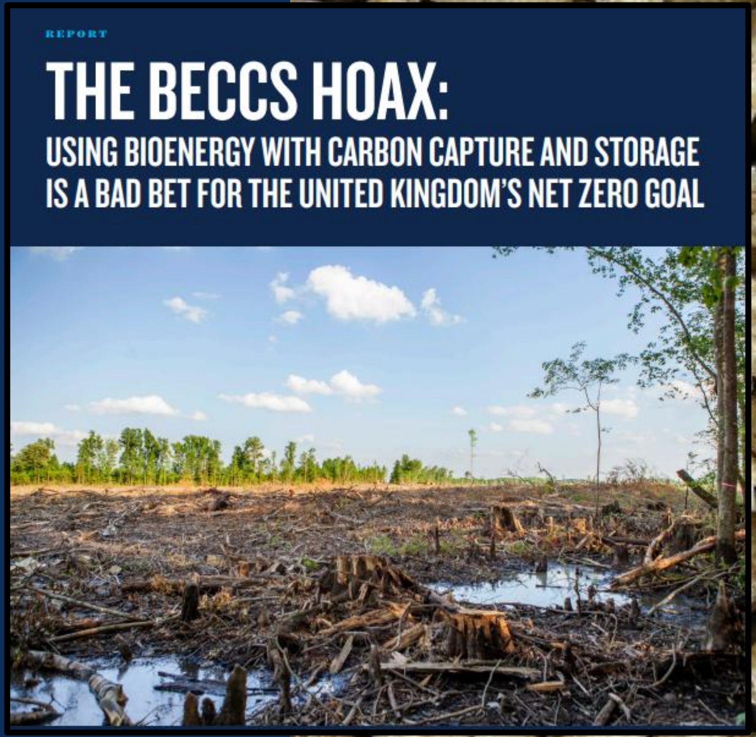


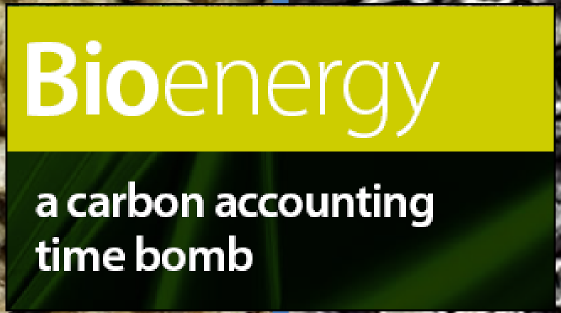
IEA NZE Scenario Net Zero emissions by 2050 in the global energy sector

Net Zero Roadmap
2023 Update

TES: Total energy supply

Biomass worse than fossil fuel?





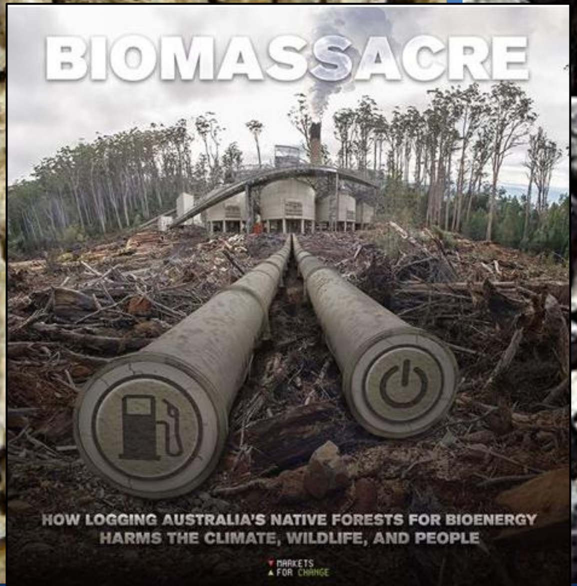
EWG > Agmag > How Corn Ethanol Is Worse For Climate Change Than The Keystone Pipeline

How Corn Ethanol Is Worse For Climate Change Than The Keystone Pipeline

By Emily Cassidy, Former Research Analyst

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change

Timothy Searchinger[1,*], Ralph Heimlich[2], R. A. Houghton[3], Fengxia Dong[4], Amani Elobeid[4], Jacinto Fabiosa[4], Simla Tokgoz[4]...



Biomass feedstocks

Forestry residues

Sawmill residues

Crop straw

Piggery manure

Horticulture residues

Feedlot Manure

Green waste

Energy crops

Short rotation woody crops

Food residues & waste

Biosolids

Poultry litter

Construction waste

Bioenergy conversion technologies

- Combustion
- Pyrolysis
- Gasification
- Fermentation
- Transesterification
- Anaerobic digestion

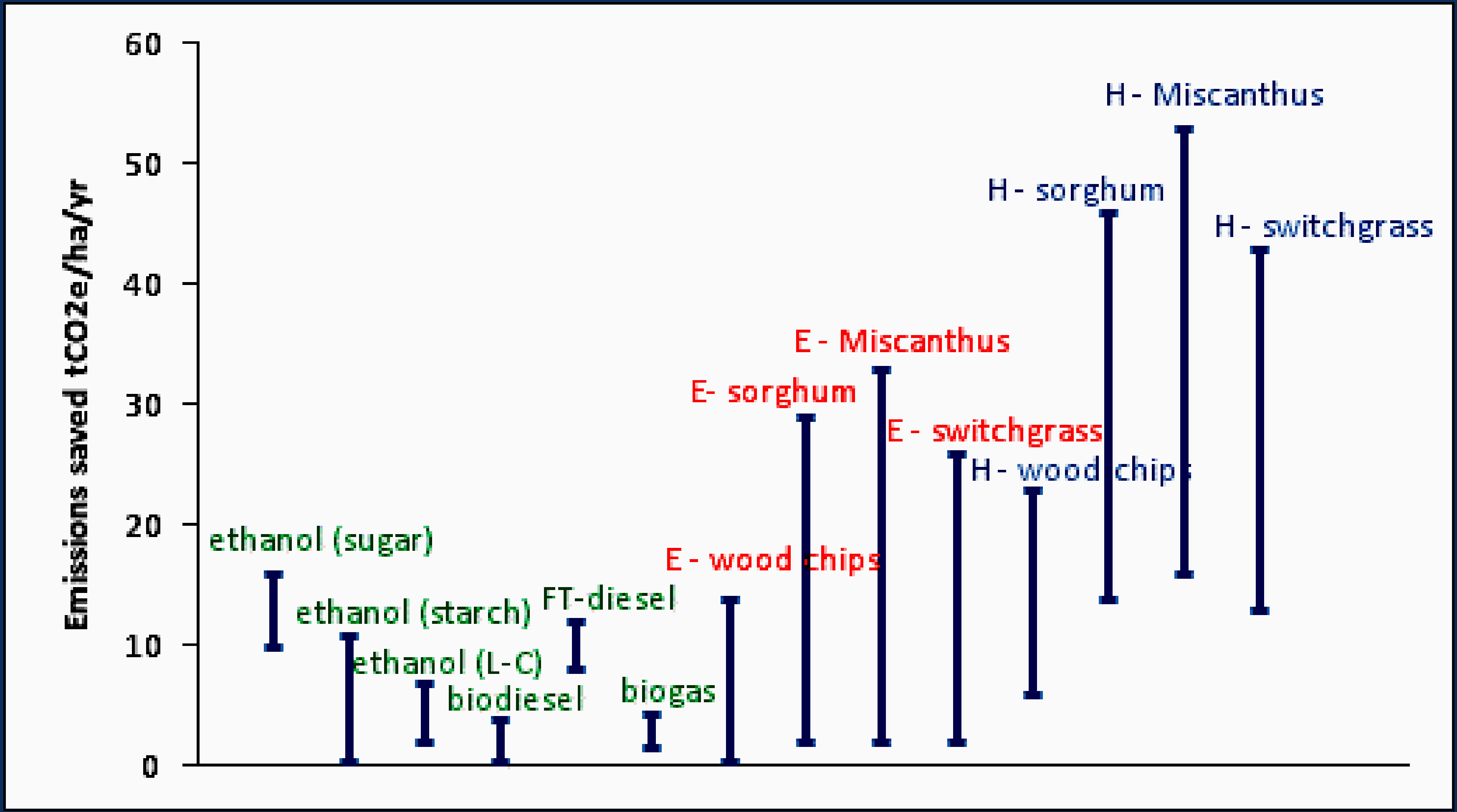
Energy products, end uses

- Pellets, woodchips
- Ethanol, biodiesel, renewable diesel
- Biogas, biomethane
- Syngas, pyrolysis oil

Used for

- Heat
- Electricity
- Transport

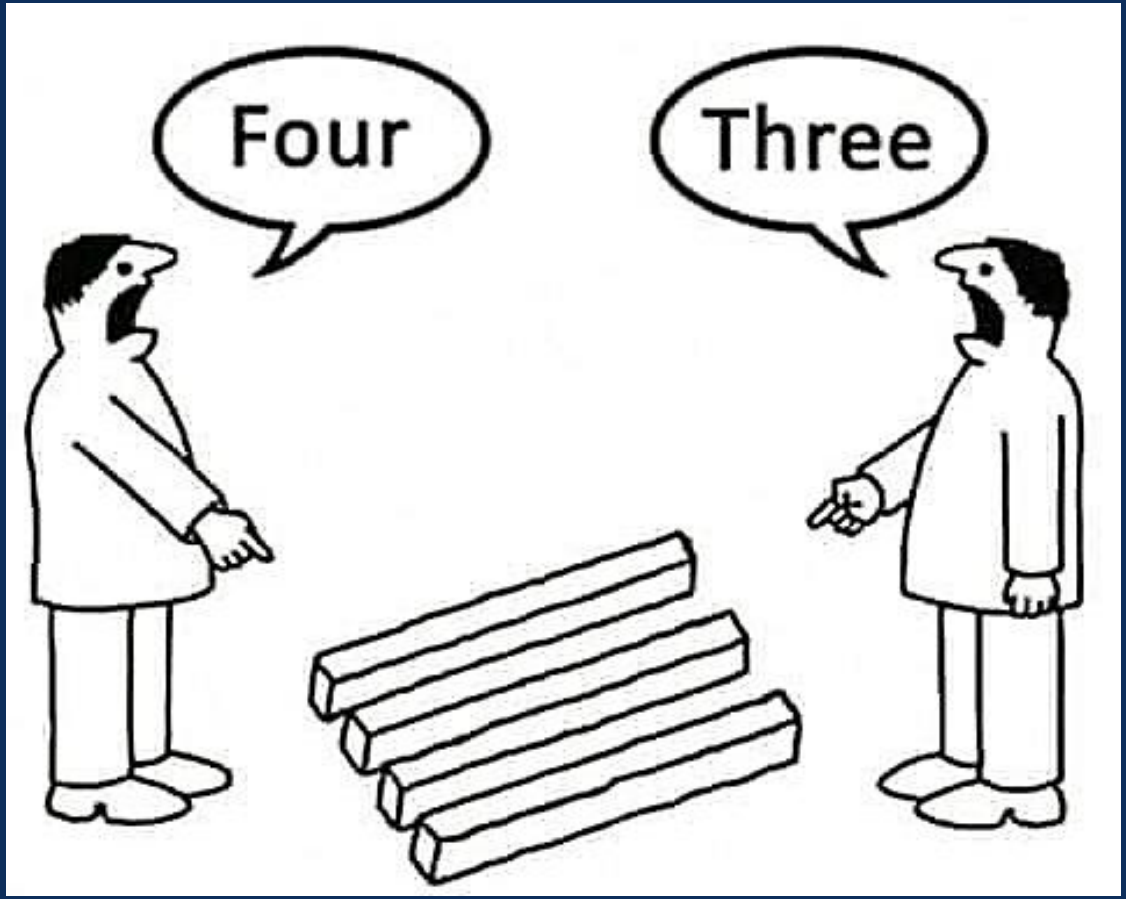
Range in results across supply chains



Excludes indirect land use change

Data from Cherubini et al 2009

Different Analytical methods



IEA Bioenergy publications on GHG accounting methodology for bioenergy

Journal papers:

- **Towards a standard methodology for greenhouse gas balances of bioenergy systems in comparison with fossil energy systems.** Schlamadinger et al., 1997. *Biomass and bioenergy, 13:359-375*.
- **Energy-and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations**. Cherubini et al., 2009. *Resources, conservation and recycling*, *53:* 434-447.
- **Quantifying the climate effects of bioenergy– choice of reference system.** Koponen et al., 2018. *Renewable and Sustainable Energy Reviews*, *81:*2271-2280.
- **Quantifying the climate change effects of bioenergy systems: Comparison of 15 impact assessment methods**. Brandão et al 2019. *GCB Bioenergy*, *11:* 727-743.
- **Evaluating metrics for quantifying the climate-change effects of land-based carbon fluxes**. Brandão et al., 2024. IJLCA 29(2), pp.328-343.

Received: 7 March 2020 | Accepted: 16 April 2021

DOI: 10.1111/gcbb.12844

GCB-BIOENERGY WILEY

RESEARCH REVIEW

Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy

Annette L. Cowie[1] | Göran Berndes[2] | Niclas Scott Bentsen[3] | Miguel Brandão[4] | Francesco Cherubini[5] | Gustaf Egnell[6] | Brendan George[7] | Leif Gustavsson[8] | Marc Hanewinkel[9] | Zoe M. Harris[10,11] | Filip Johnsson[2] | Martin Junginger[12] | Keith L. Kline[13] | Kati Koponen[14] | Jaap Koppejan[15] | Florian Kraxner[16] | Patrick Lamers[17] | Stefan Majer[18] | Eric Marland[19] | Gert-Jan Nabuurs[20] | Luc Pelkmans[21] | Roger Sathre[8] | Marcus Schaub[22] | Charles Tattersall Smith Jr.[23] | Sampo Soimakallio[24] | Floor Van Der Hilst[12] | Jeremy Woods[10] | Fabiano A. Ximenes[25]

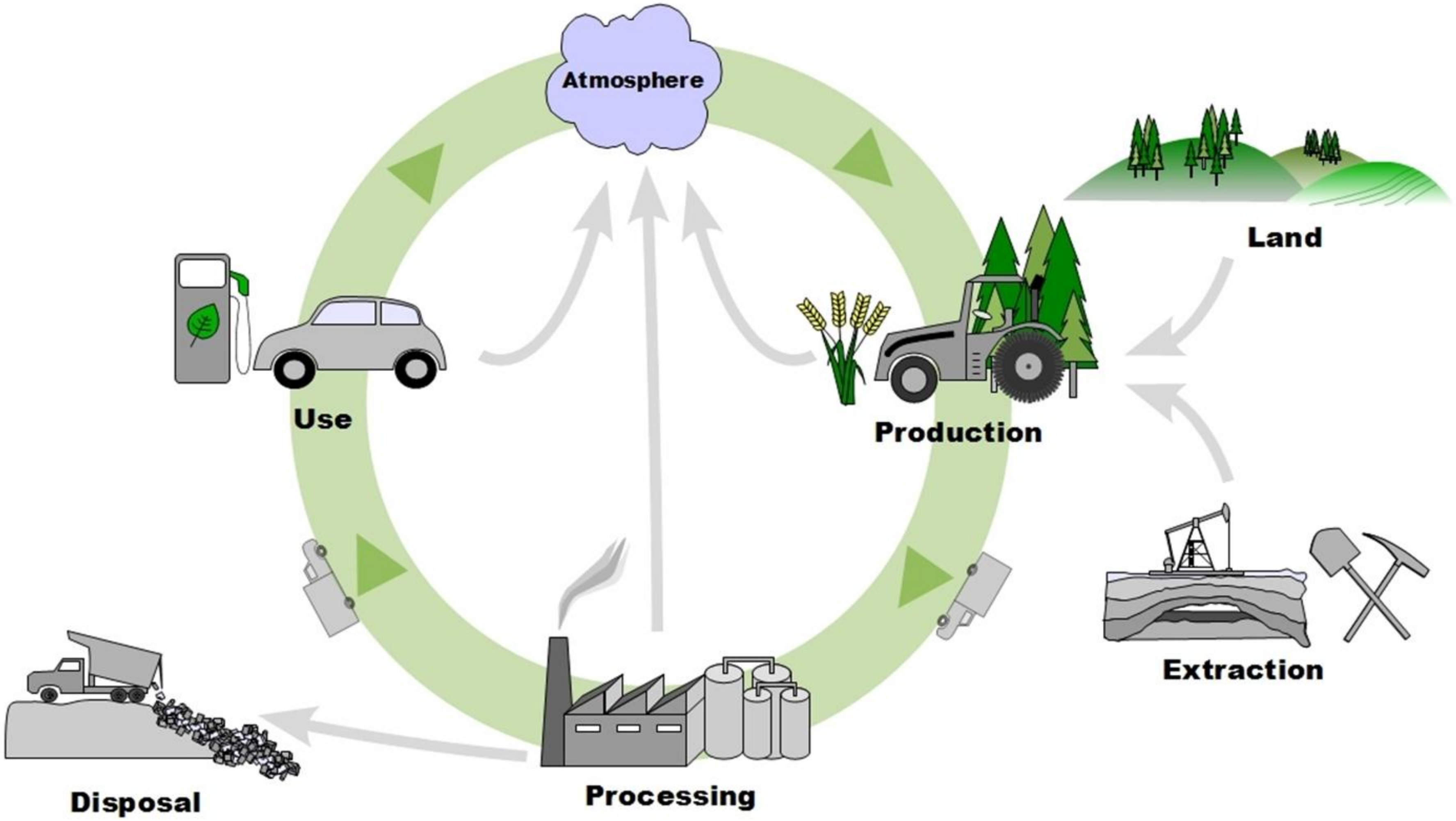
Global Change Biology Bioenergy
BIOPRODUCTS FOR A SUSTAINABLE BIOECONOMY

REVIEW OPEN ACCESS

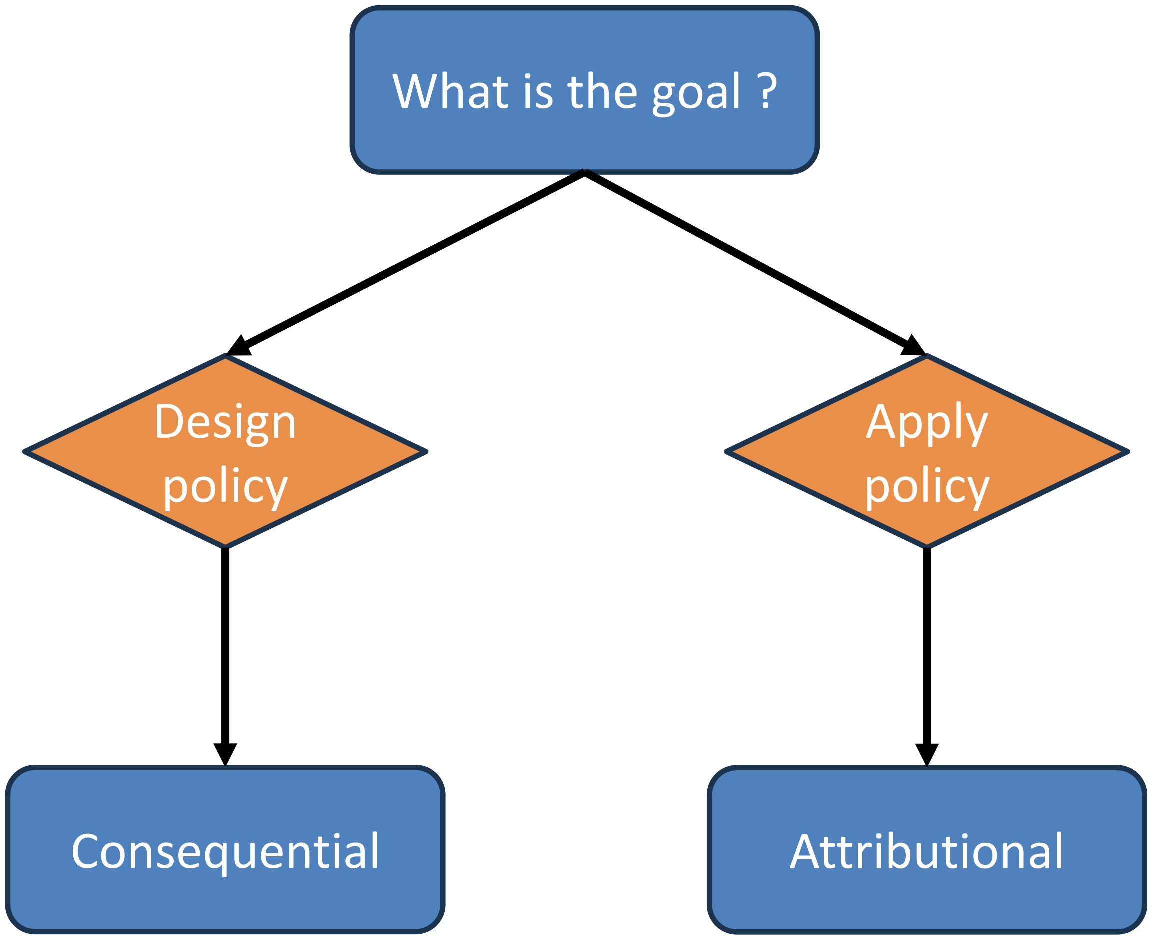
Quantifying Climate Change Effects of Bioenergy and BECCS: Critical Considerations and Guidance on Methodology

Annette Cowie[1,2] | Kati Koponen[3] | Anthony Benoist[4,5,6] | Göran Berndes[7] | Miguel Brandão[8,9,10] | Leif Gustavsson[11] | Patrick Lamers[12] | Eric Marland[13] | Sebastian Rüter[14] | Sampo Soimakallio[15] | David Styles[16]

Life cycle perspective



Modelling approach: Attributional vs consequential



Scope:
Sources and sinks included – carbon pools

- C stock change in plants and soil
- direct land use change - dLUC
- change in management practice

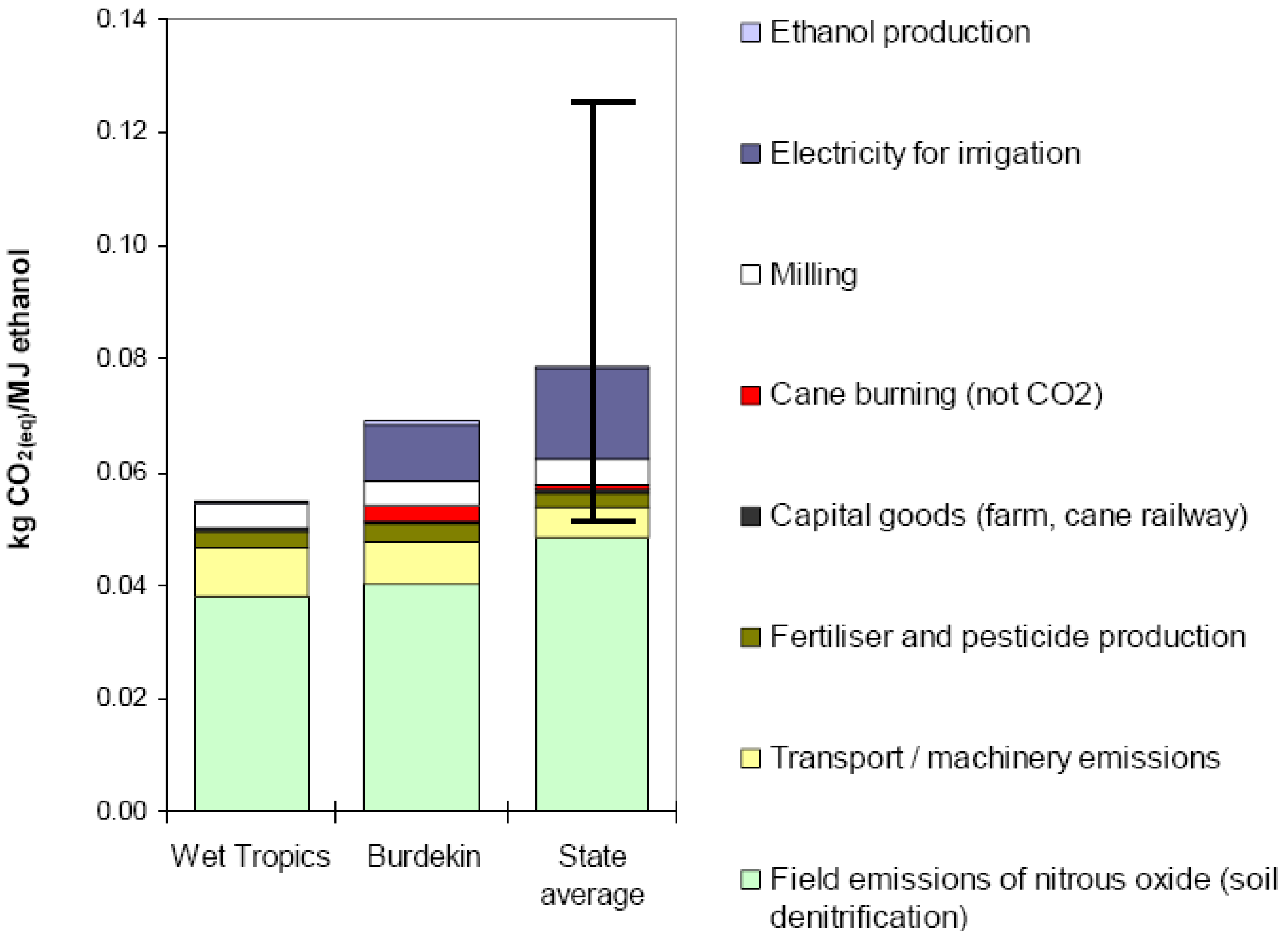


Direct land use change dLUC

Previous land use is critical

- Forest to energy crop
- Pasture
- Degraded land

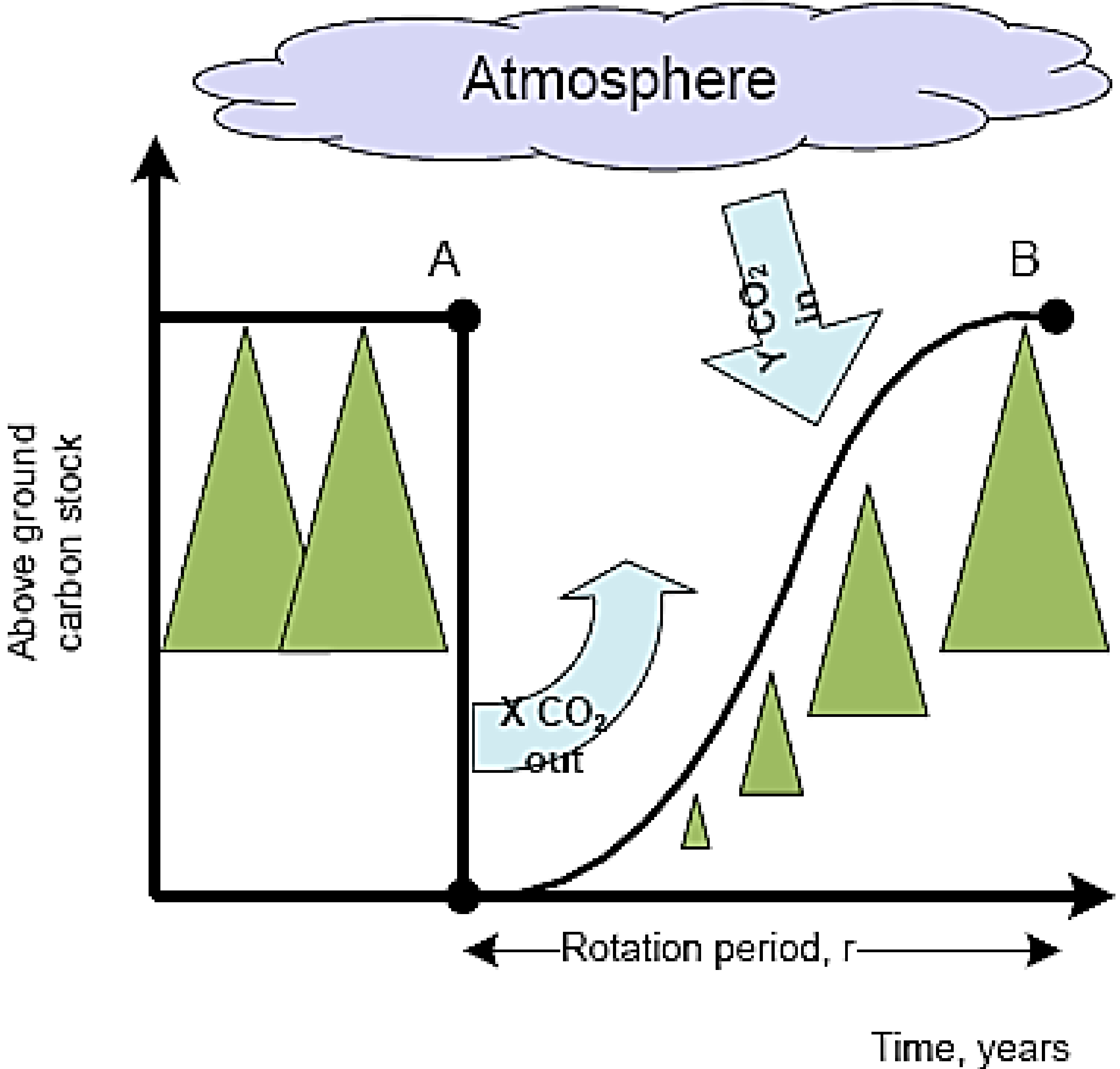
Scope: GHGs included



Carbon footprint of cane ethanol, Qld

M. Renouf 2007

Spatial scale - stand



F Cherubini NTNU

Spatial scale - landscape

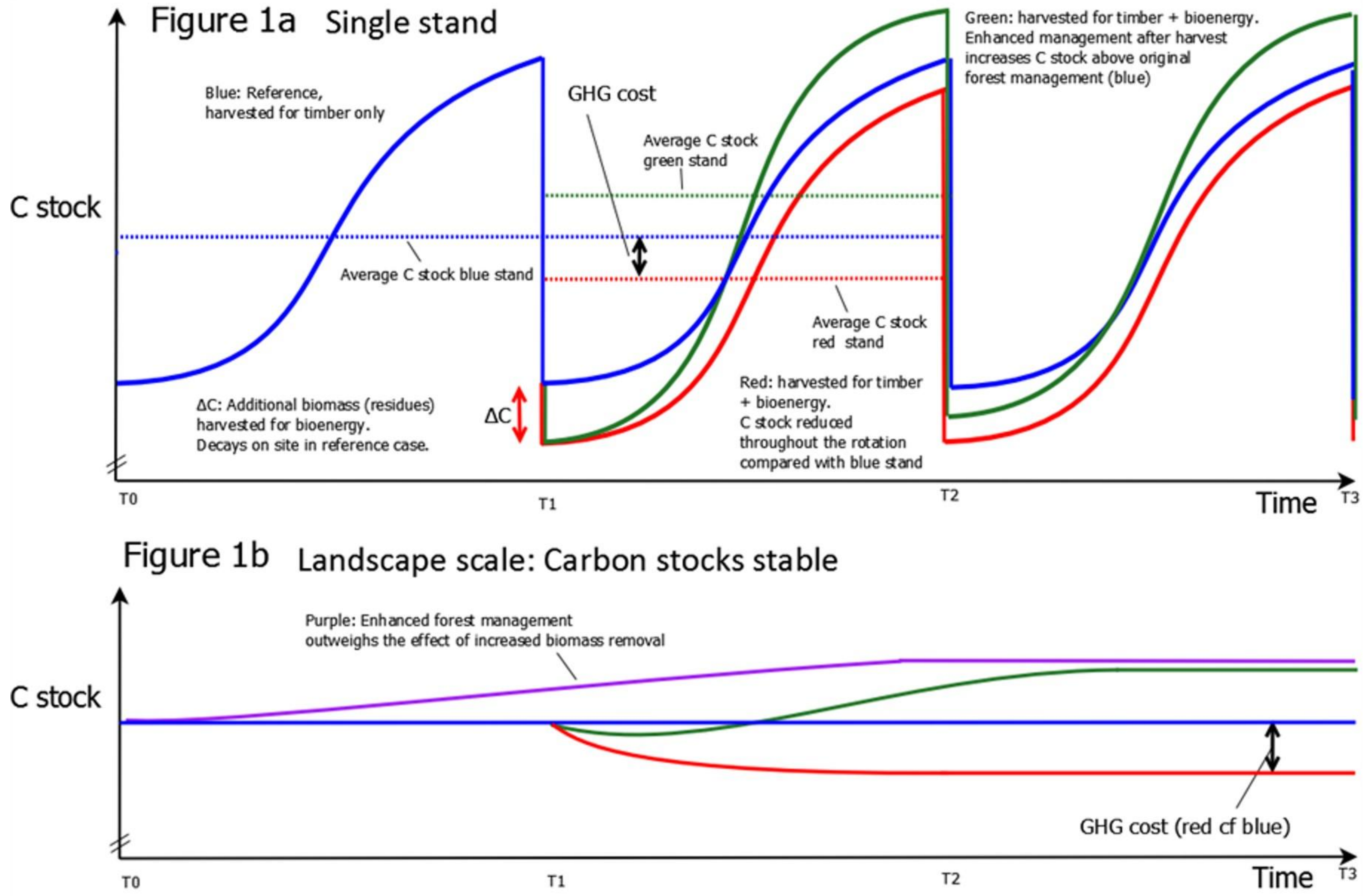
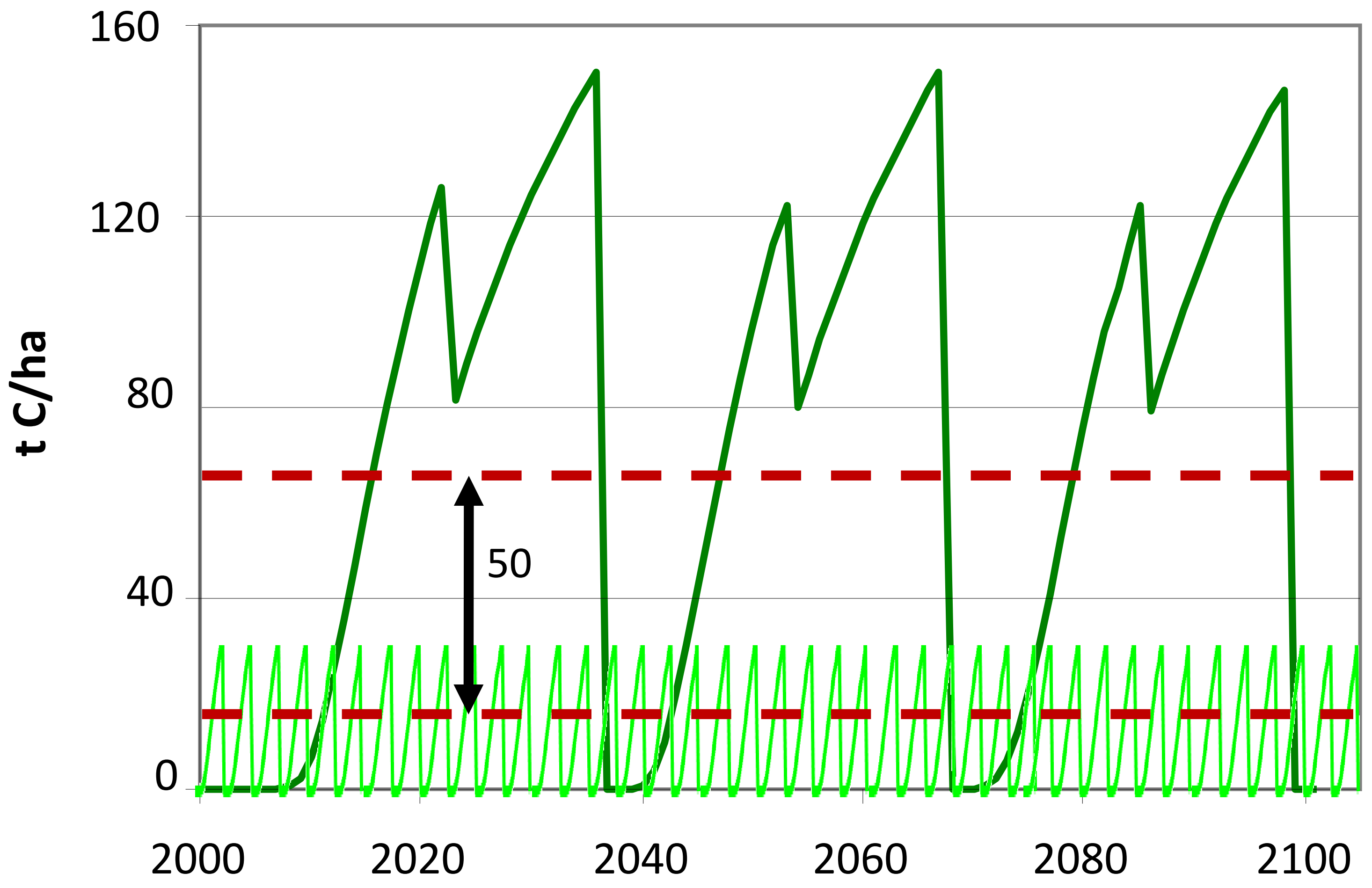
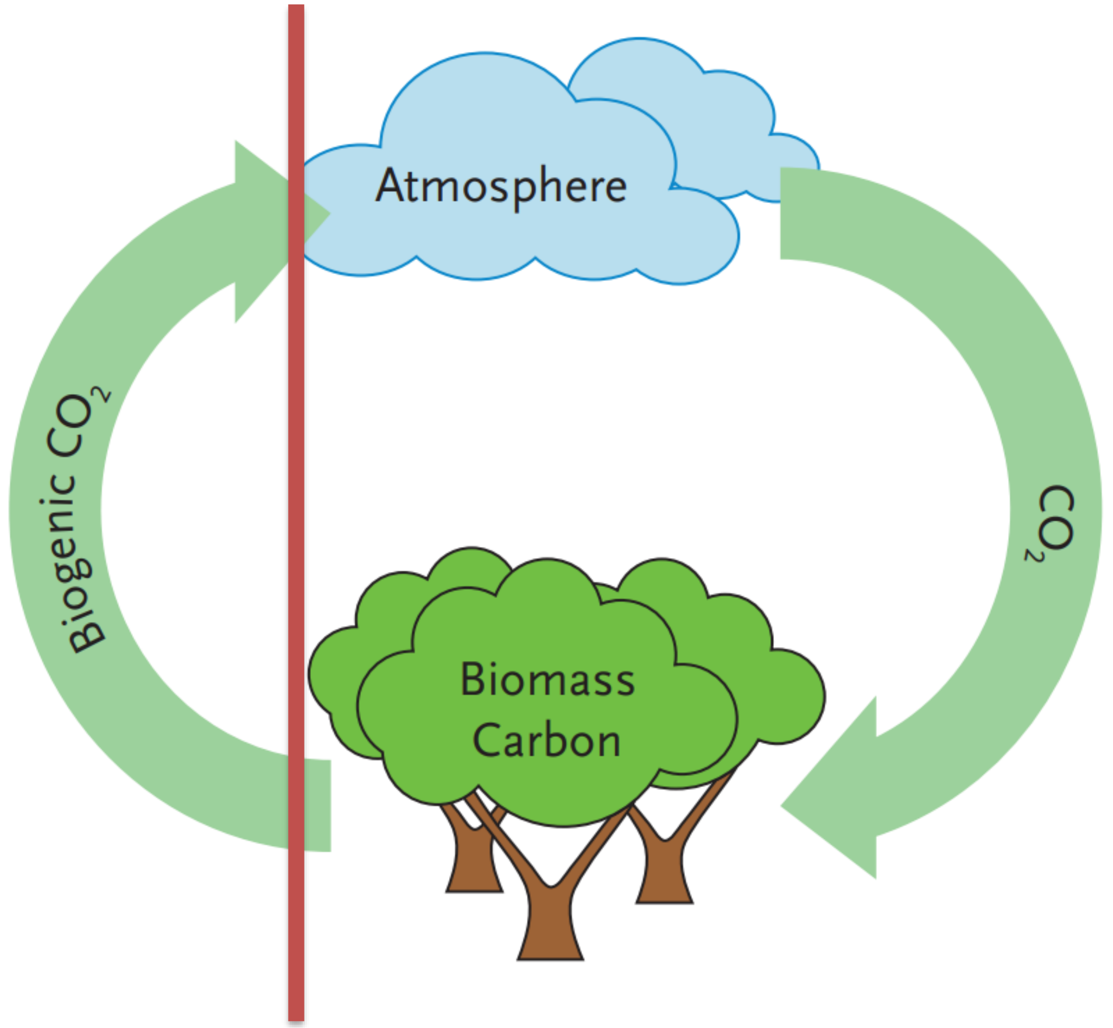


Figure 1a Single stand
C stock
Blue: Reference,
harvested for timber only
GHG cost
Average C stock
green stand
Green: harvested for timber + bioenergy.
Enhanced management after harvest
increases C stock above original
forest management (blue)
Average C stock blue stand
Average C stock
red stand
ΔC: Additional biomass (residues)
harvested for bioenergy.
Decays on site in reference case.
ΔC
Red: harvested for timber
+ bioenergy.
C stock reduced
throughout the rotation
compared with blue stand
T0
T1
T2
Time
T3
Figure 1b Landscape scale: Carbon stocks stable
C stock
Purple: Enhanced forest management
outweighs the effect of increased biomass removal
GHG cost (red cf blue)
T0
T1
T2
Time
T3

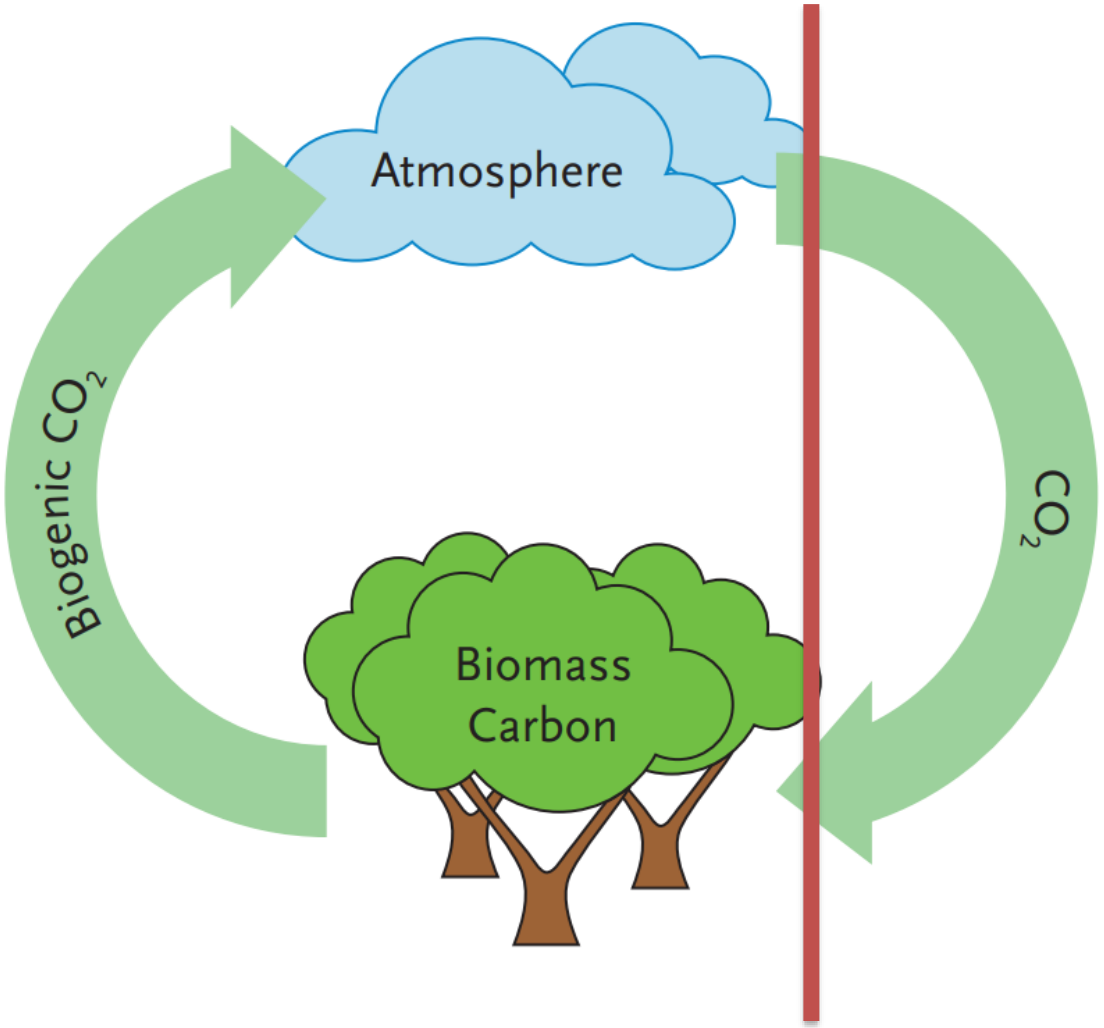
Biomass carbon stock change



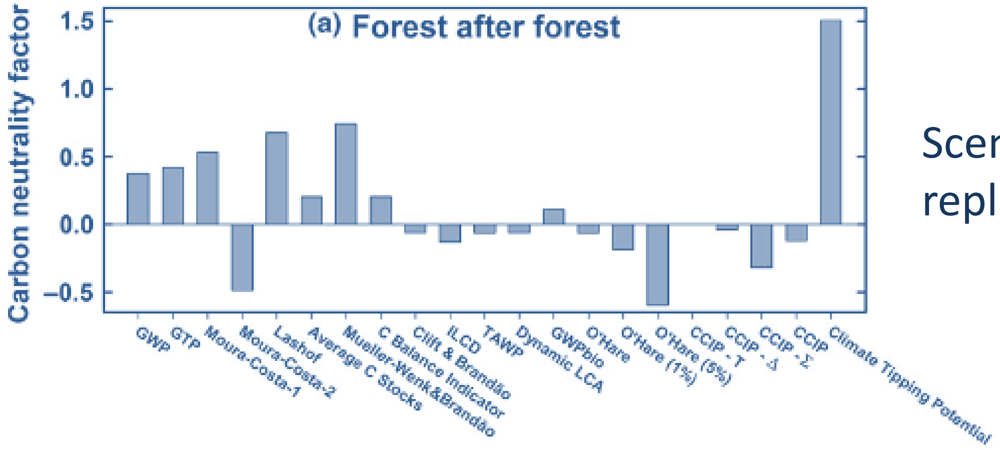
Time: When to start counting?



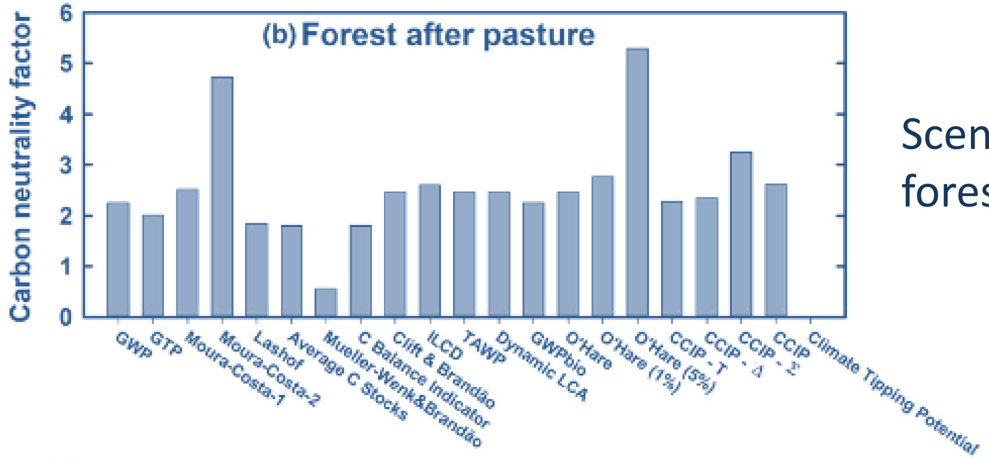
Time: When to start counting?



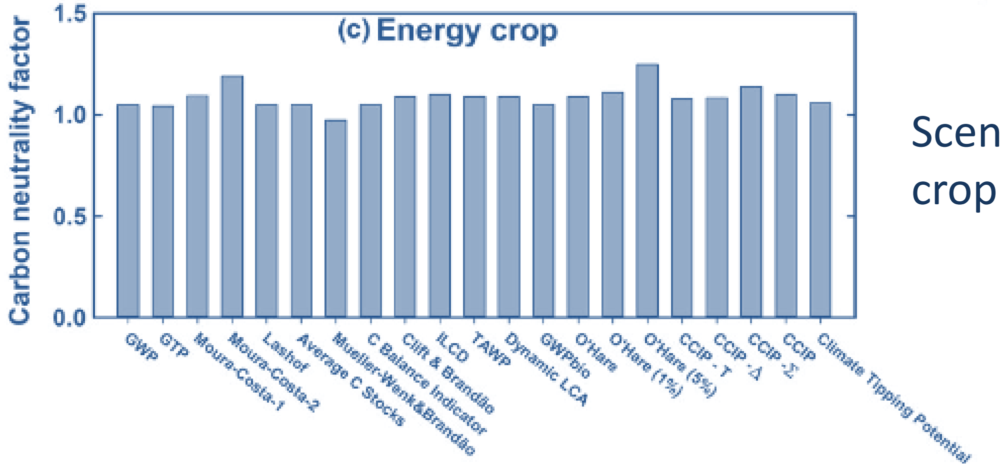
Climate impact assessment method



Scenario 1: bioenergy forest replaces carbon-rich forest



Scenario 2: bioenergy forest replaces pasture



Scenario 3: annual energy crop on cropland

CN > 1 – additional	**Better than carbon neutral sequestration**
CN = 1	**Carbon neutral**
1 > CN > 0	**Not carbon neutral, but better than fossil fuels**
CN < 0	**Worse than fossil-fuels**

Brandão et al, 2018

Handling multifunction product systems

Following ISO 14044 / ISO 14067 :

1. Where possible, avoid allocation by:

a. subdivision: Divide the product system into sub-processes, such that inputs and outputs specific to the studied co-product are separated

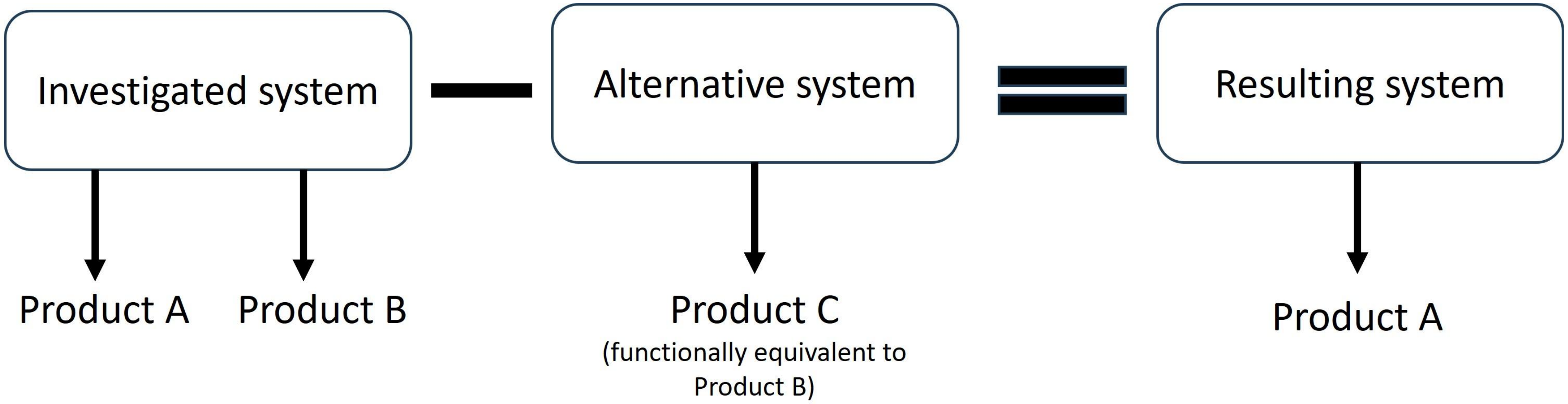
b. system expansion (with substitution): Expand the system boundary to include all functions related to co-products

2. Allocation: Share inputs and outputs between co-products on the basis of:

a. underlying physical relationship

b. other relationship such as mass, energy, economic value

System expansion with substitution (Consequential)



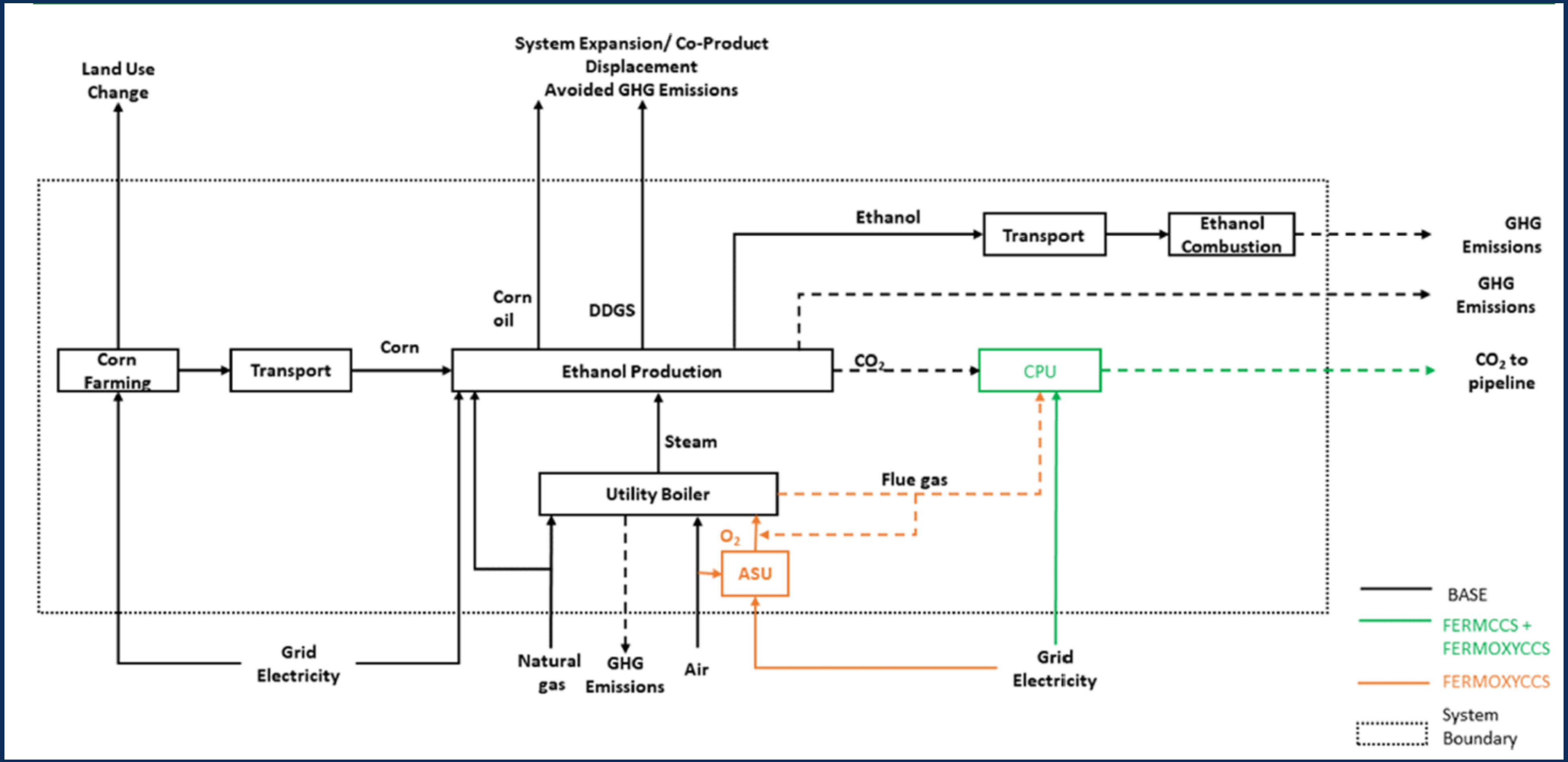
Cowie et al., 2023 Adapted from ISO 13065

Handling co-products

Environmental Science & Technology
pubs.acs.org/est
Article

Cost and Life Cycle Emissions of Ethanol Produced with an Oxyfuel Boiler and Carbon Capture and Storage

John Dees, Kafayat Oke, Hannah Goldstein, Sean T. McCoy, Daniel L. Sanchez,* A. J. Simon, and Wenqin Li

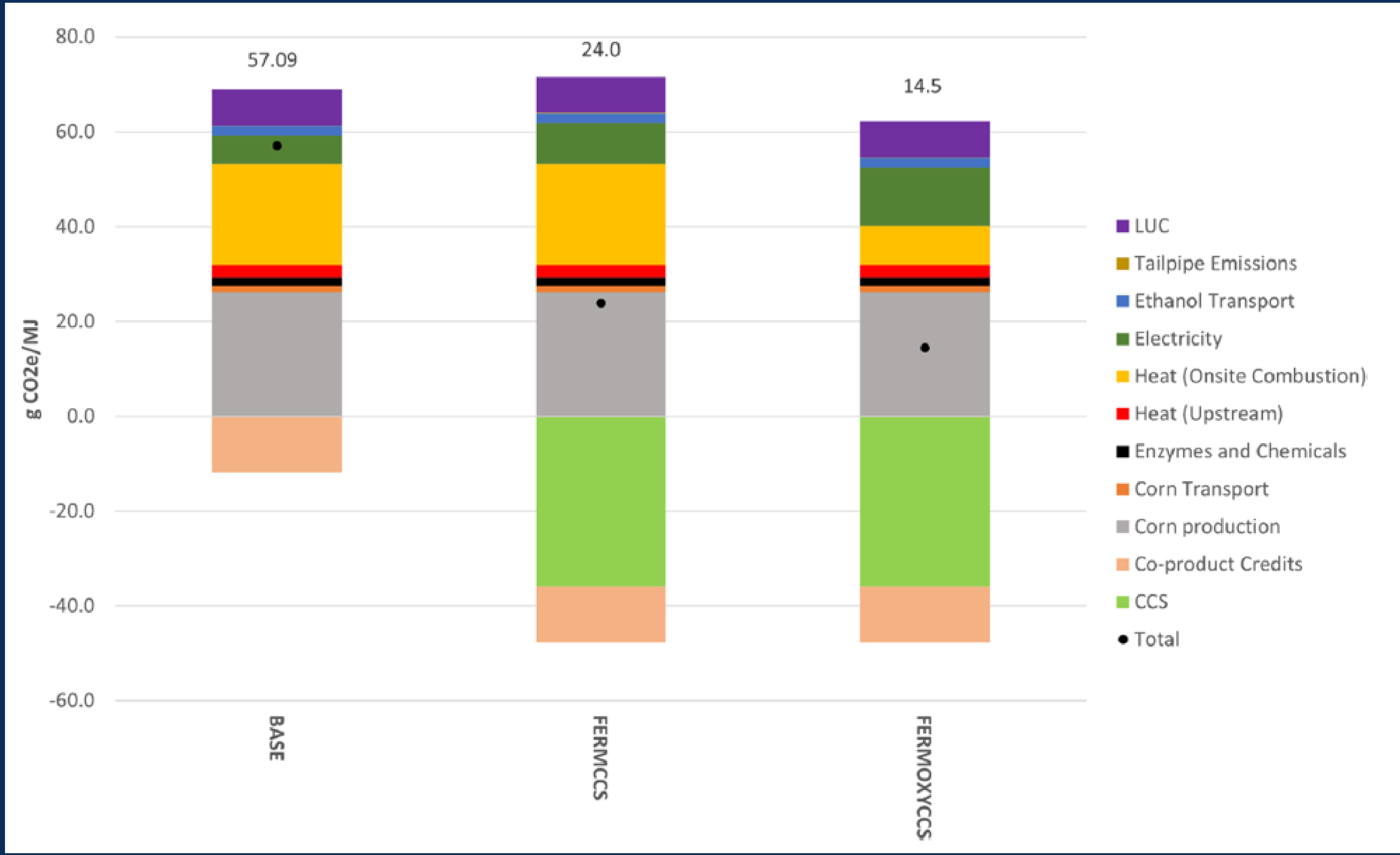


Environmental Science & Technology
pubs.acs.org/est
Article

Cost and Life Cycle Emissions of Ethanol Produced with an Oxyfuel Boiler and Carbon Capture and Storage

John Dees, Kafayat Oke, Hannah Goldstein, Sean T. McCoy, Daniel L. Sanchez,* A. J. Simon, and Wenqin Li

Handling co-products



Corn ethanol with CCS
System expansion to share emissions between ethanol, DDGS, corn oil

Base:
57 gCO2e/MJ
FERMCCS:
24 gCO2e/MJ
FERMOXYCCS:
15 gCO2e/MJ

(Dees et al., 2023)

Reference land use

- Timber without bioenergy?
- Conservation forest?
- Purpose-grown crop?
- Displaced production?
- Marginal land?







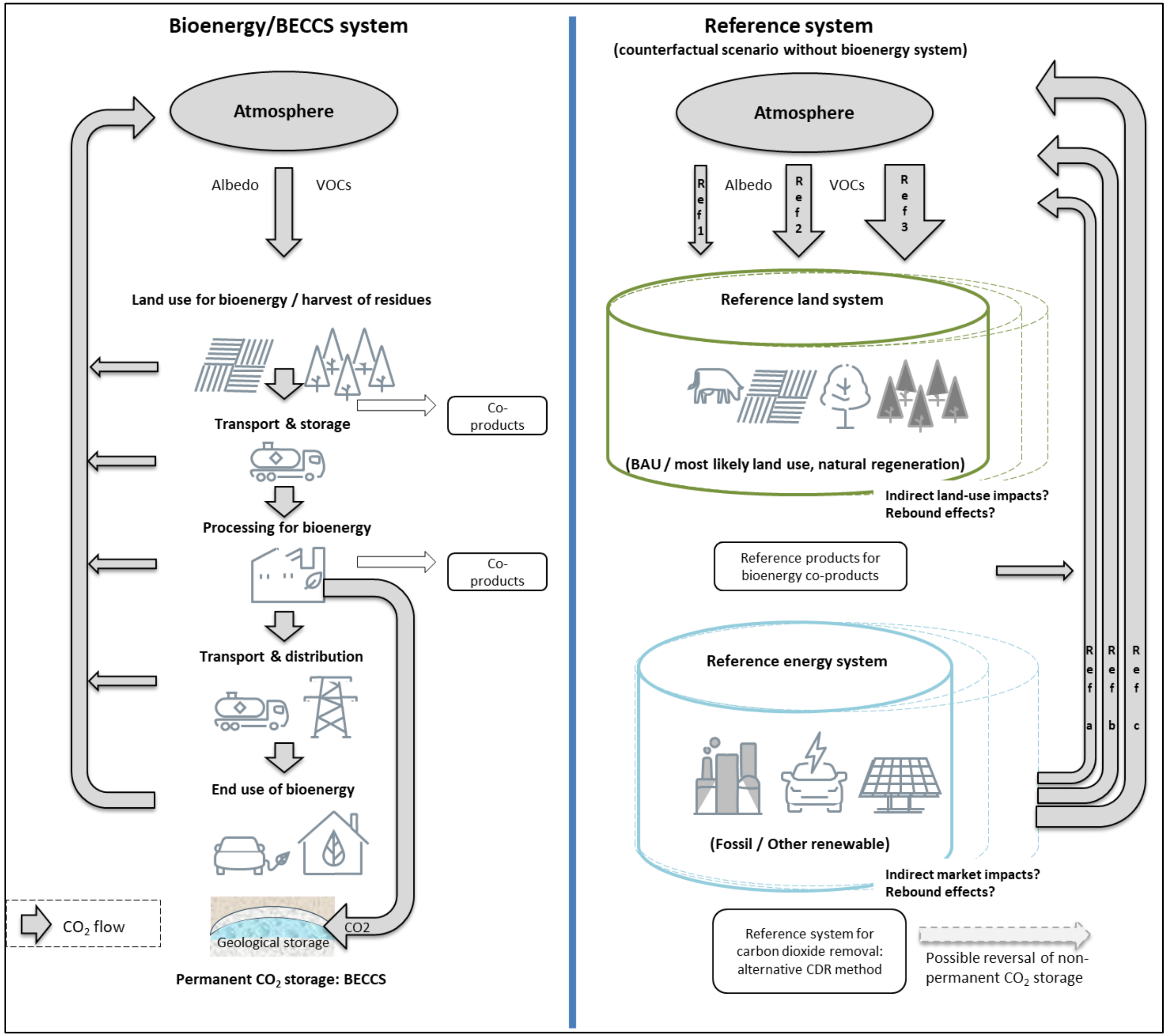


Reference
fate of biomass






Compare bioenergy with reference scenario(s)



Recommended approach to assessing climate change effects of bioenergy systems: compare bioenergy with reference system providing same service

Cowie et al., 2025

	(1) Choose relevant LCA approach according to the goal of the study:	
(2) Define modelling choices according to the LCA approach selected:	**Micro-scale decisions, compliance testing (ALCA)**	**Policy development and other major decisions (CLCA)**
Functional Unit:	E.g. 1 MJ of bioenergy BECCS: t CO2 removed	Change in supply of the functional unit due to the bioenergy of BECCS system studied
Land reference system/scenario:	Natural regeneration (where relevant)	Most likely alternative land system
Energy reference system/scenario:	Fossil / other bioenergy / other renewable	Fossil / other bioenergy / other renewable
CDR reference system for BECCS:	Other CDR method	Other CDR method
Spatial boundary:	Stand /Landscape / Regional	Landscape / Regional
Temporal boundary:	Retrospective / Prospective	Retrospective / Prospective
System boundary:	Indirect market-mediated impacts excluded	Direct and indirect market-mediated impacts included
Allocation method:	Allocation based on attribute (mass, LHV, value)	System expansion

(3) LCI / LCA analysis + uncertainty & sensitivity analysis

(4) Interpret and communicate the results coherently with the goal and the methods chosen

Checklist

for analysing the climate effects of bioenergy systems using methods consistent with the goal of the study

Cowie et al., 2025

Key messages

- Methodology has a strong influence on the results
  - Scope – sources and sinks included
  - System boundary – spatial and temporal
  - Reference land use/biomass fate
  - Functional unit
- Choose methods consistent with the goal
- For policy design, indirect effects must be considered
  - Consequential approach
- For policy implementation, consistency, comparability, control are key
  - Attributional approach

Recommendations

- Apply a comprehensive approach to climate impact assessments when the goal is to support decision-making.
- Key choices include the reference land use and energy system that bioenergy is assumed to displace, spatial and temporal system boundaries, co-product handling, climate forcers considered, metrics applied and time horizon of impact assessment.
- To enhance comparability, provide LCI data and detail methods
- Interpretation of the results must be consistent with the methodology and assumptions chosen, and uncertainties and context-specificity must be disclosed.

For further information:

Annette.cowie@dpi.nsw.gov.au

Cowie et al. **Quantifying climate change effects of bioenergy and BECCS: critical considerations and guidance on methodology**
Global Change Biology Bioenergy

IEA Bioenergy
Technology Collaboration Programme

www.ieabioenergy.com