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Measured greenhouse gas budgets challenge emission savings from palm-oil biodiesel

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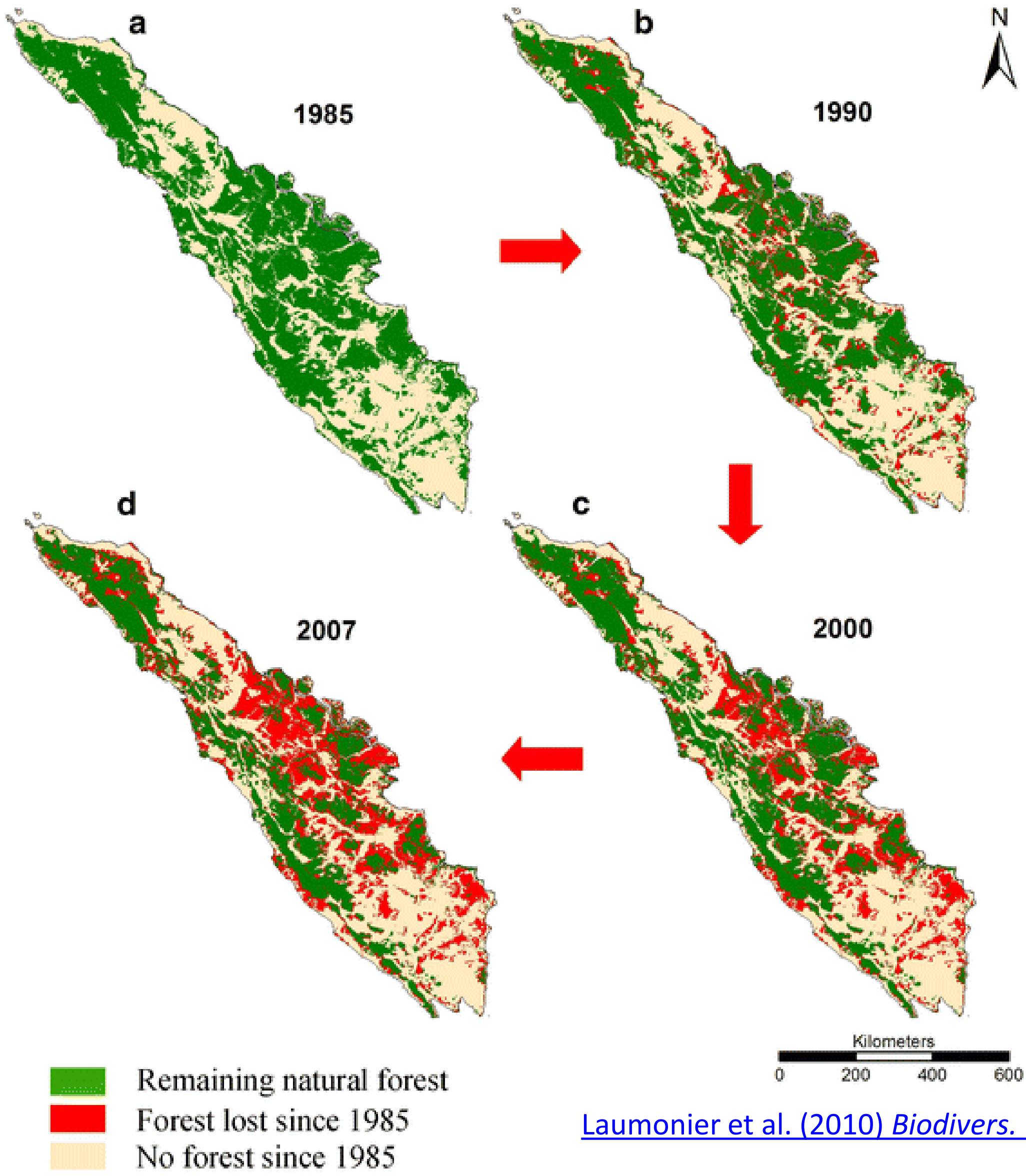
Meijide, A., de la Rua, C., Guillaume, T. *et al.* Measured greenhouse gas budgets challenge emission savings from palm-oil biodiesel. *Nat Commun* **11,** 1089 (2020). https://doi.org/10.1038/s41467-020-14852-6

Forest cover in Sumatra, Indonesia



- Large decreases of forest cover in Sumatra, Indonesia during the last years
- Oil palm expansion is one of the main causes of forest loss

[Laumonier et al. (2010) *Biodivers. Conserv.*]

Biofuels

- Biofuels were considered an alternative to reduce GHG emissions from fossil fuels ➔ politically endorsed
- Debate regarding benefits of biofuels increasing
  - Studies show **+** and **–** effects on GHG emissions
- No full greenhouse gas (GHG) budget (considering net CO_2, CH_4 and N_2O fluxes) available for oil palm plantations, or considering plantation age
- Studies on the effect of palm-oil biodiesel not based on measured GHG budgets

EU regulation regarding biofuels

- Renewable Energy Directive (REW) of the EU (2009,modified in 2018): biofuels must reach
  - at least 60% GHG emission savings for biofuels that start production operation before 2020,
  - at least 65% for operations starting between 2021 and 2026, and
  - at least 80% for operations after 2026.
- Life cycle analysis (LCA) is the methodology used to assess the saving
  - LCA considers biofuels as CO_2 neutral: CO_2 absorbed in cultivation = CO_2 released when burning biodiesel ➔ "C neutrality assumption"
  - LCA based on field measured data not available for palm-oil biodiesel

Objectives

- Measure GHG budgets in young and mature oil palm plantations
- Compare GHG budgets for oil palm plantations in mineral and peat soils
- Provide the first LCA for palm-oil biodiesel based on field measured data for first-generation oil palm plantations
- Evaluate scenarios for increasing emission savings for palm oil biodiesel for 1st and 2nd rotation cycles

Methodology

- Measured GHG fluxes at the field level – chambers and eddy covariance
- Update LCA with our field measurements
- Develop strategies to potentially increase emission savings
- Evaluate GHG emissions from 2nd cultivation cycles

Study sites

Mean annual temperature: 26.7 ± 0.2°C

Mean annual rainfall: 2235 ± 385 mm

(1991-2011)

2 oil palm plantations in Jambi, Sumatra, Indonesia

Young – non productive
(1-year old)
8 months – (2013-2014)

Fertilization: 88 kg N ha^{-1}

Mineral soils

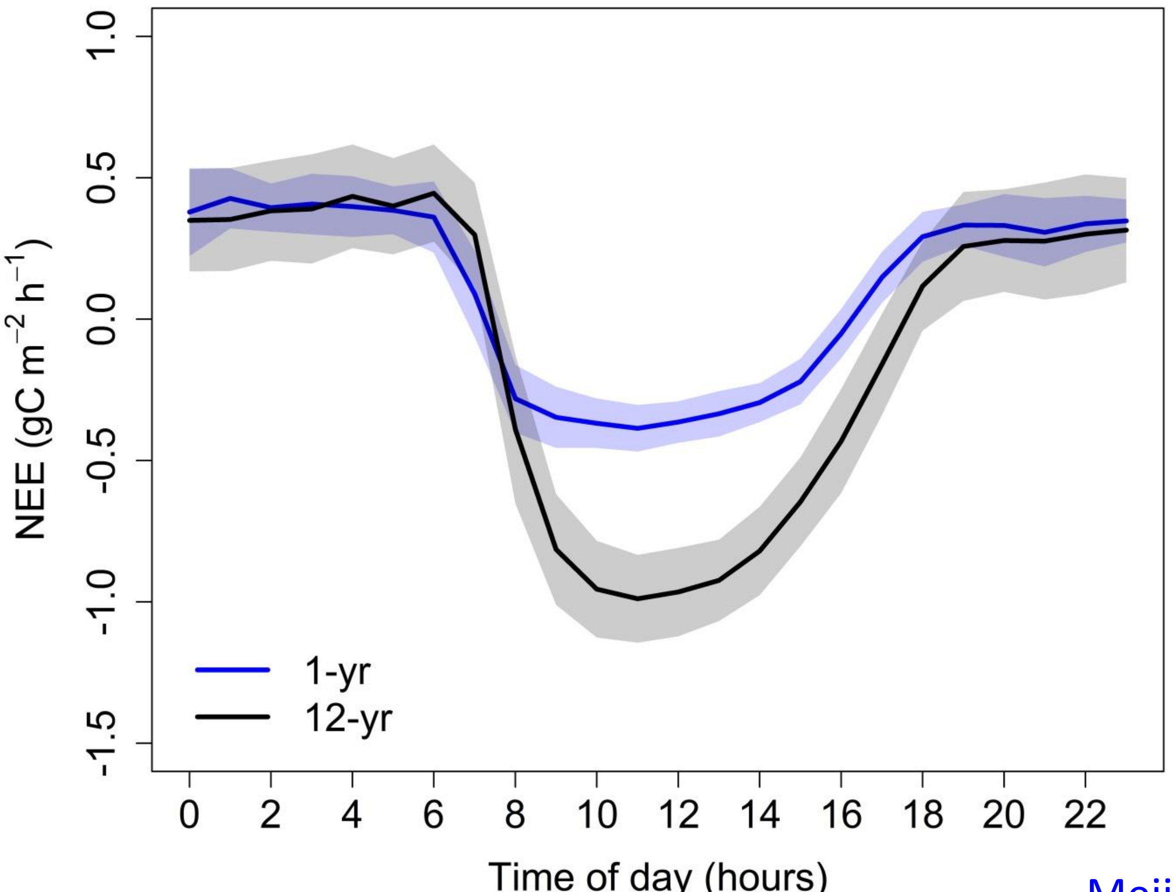
Mature – productive
(12-year old)
2 years – (2014-2016)

Fertilization: 196 kg N ha^{-1}

90% Mineral soils + 10% Peat soils

Ecosystem CO_2 measurements: eddy covariance

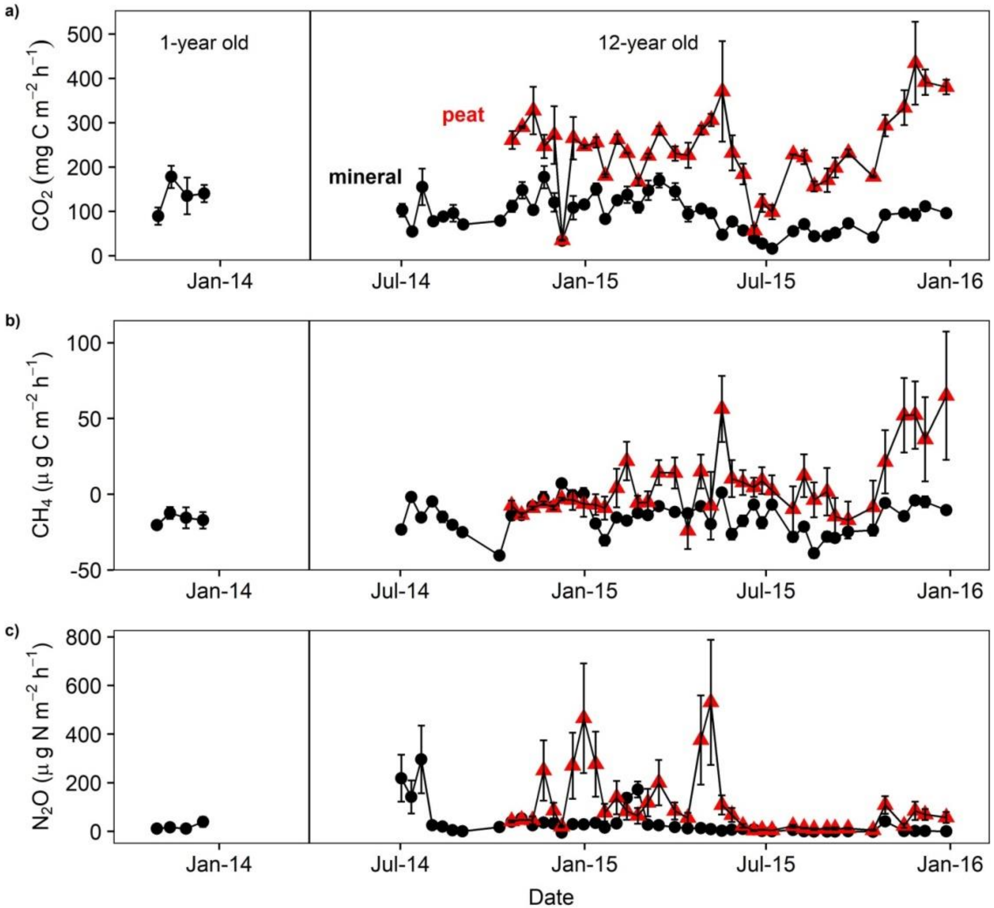
Net ecosystem CO_2 exchange (NEE): measurements every 30 min



- Uptake >> in 12-yr
- Similar night fluxes in both plantation sites
- As autotrophic respiration is smaller in 1-yr old (smaller palms), heterotrophic respiration is larger in young plantation

[Meijide et al., 2020]

Soil GHG emissions: chamber measurements



Soil respiration (mgC m^{-2} h^{-1})	
1-yr min.	133.9 ± 19.0^{a}
12-yr min.	91.7 ± 22.1^{a}
12-yr peat	239.8 ± 46.1^{b}

CH_4 (µgC m^{-2} h^{-1})	
1-yr min.	-17.0 ± 2.2^{a}
12-yr min.	-14.7 ± 4.6^{a}
12-yr peat	6.2 ± 24.0^{b}

N_2O (µgN m^{-2} h^{-1})	
1-yr min.	19.7 ± 7.9^{a}
12-yr min.	31.1 ± 21.2^{a}
12-yr peat	104.4 ± 93.6^{b}

- Similar GHG emissions from 1- and 12- yr old plantations on mineral soils
- Larger emissions from peat soils than from mineral soils

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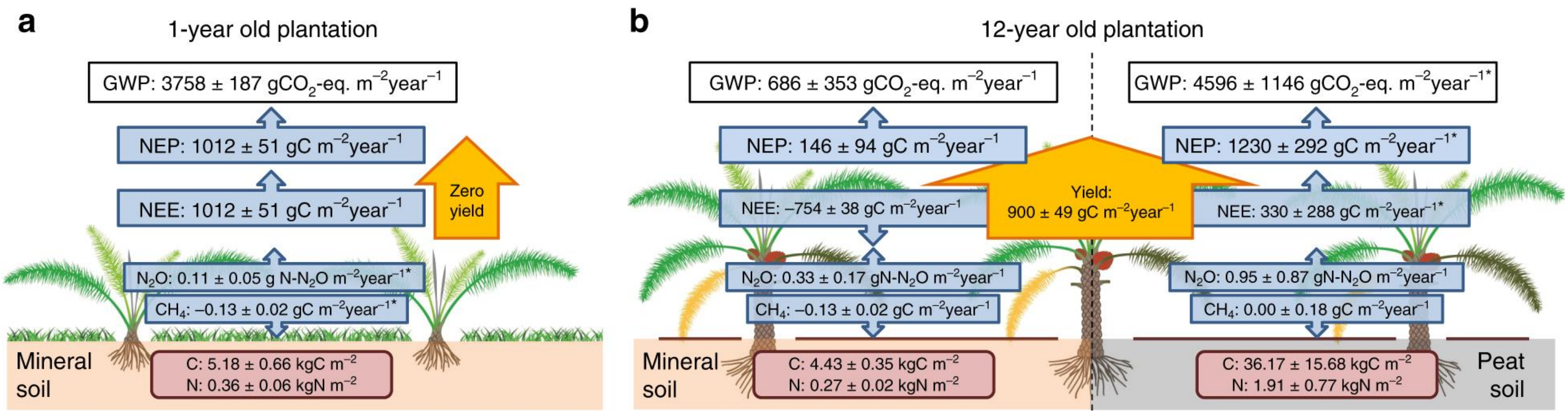
Measured GHG fluxes from plantations



* indicates that fluxes were not directly measured in our study sites but estimated from other measurements.

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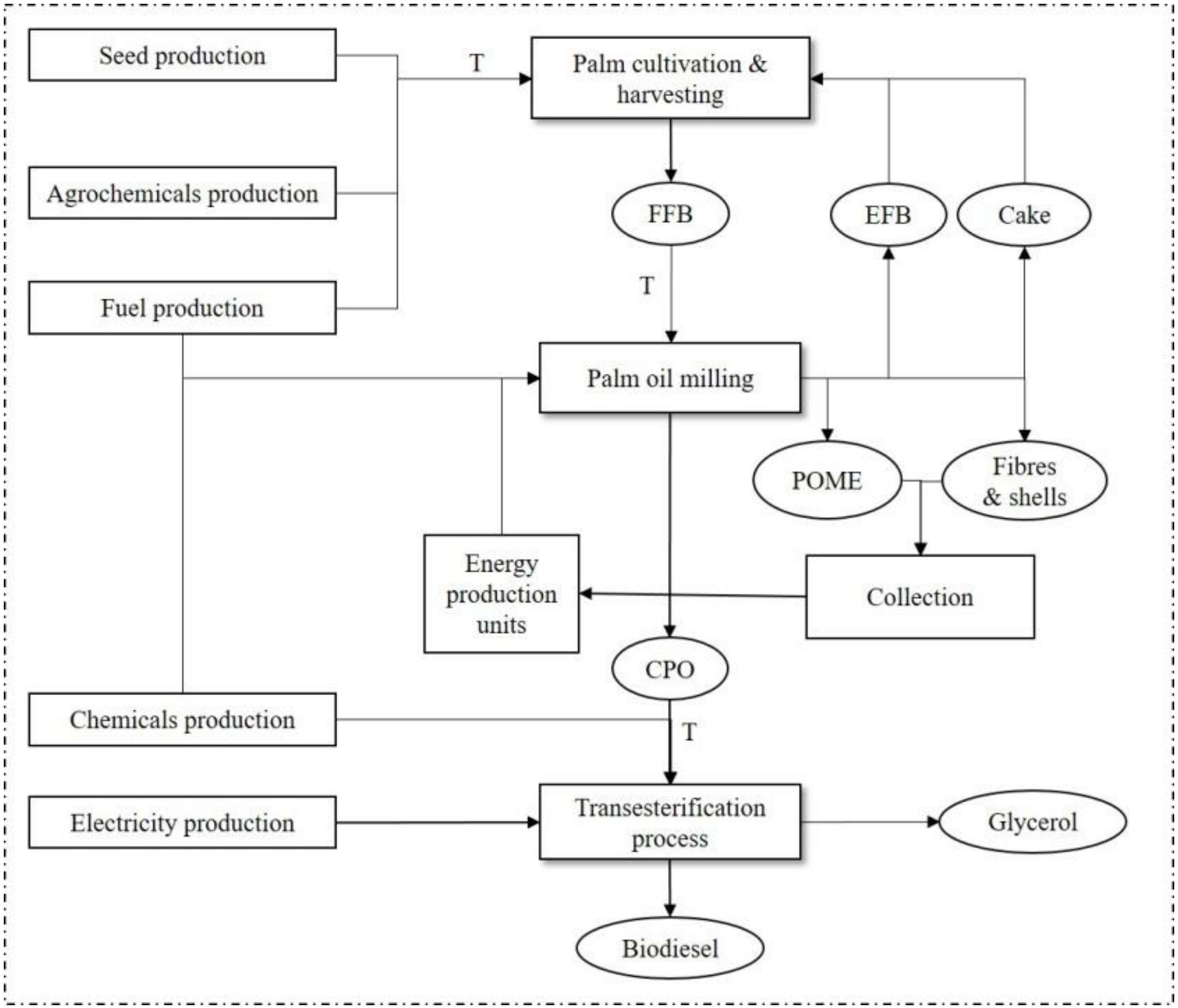
- Young plantation is a GHG source
- Mature plantation in mineral soil is a sink ➔ when harvest is considered it is also a source
- Mature plantation in peat soil is a source ➔ GWP from mature plantations in peat **7 times larger**

Life Cycle Analysis



Updated with field measurements!

System boundaries:
- **Cultivation**
- milling
- Production of biodiesel

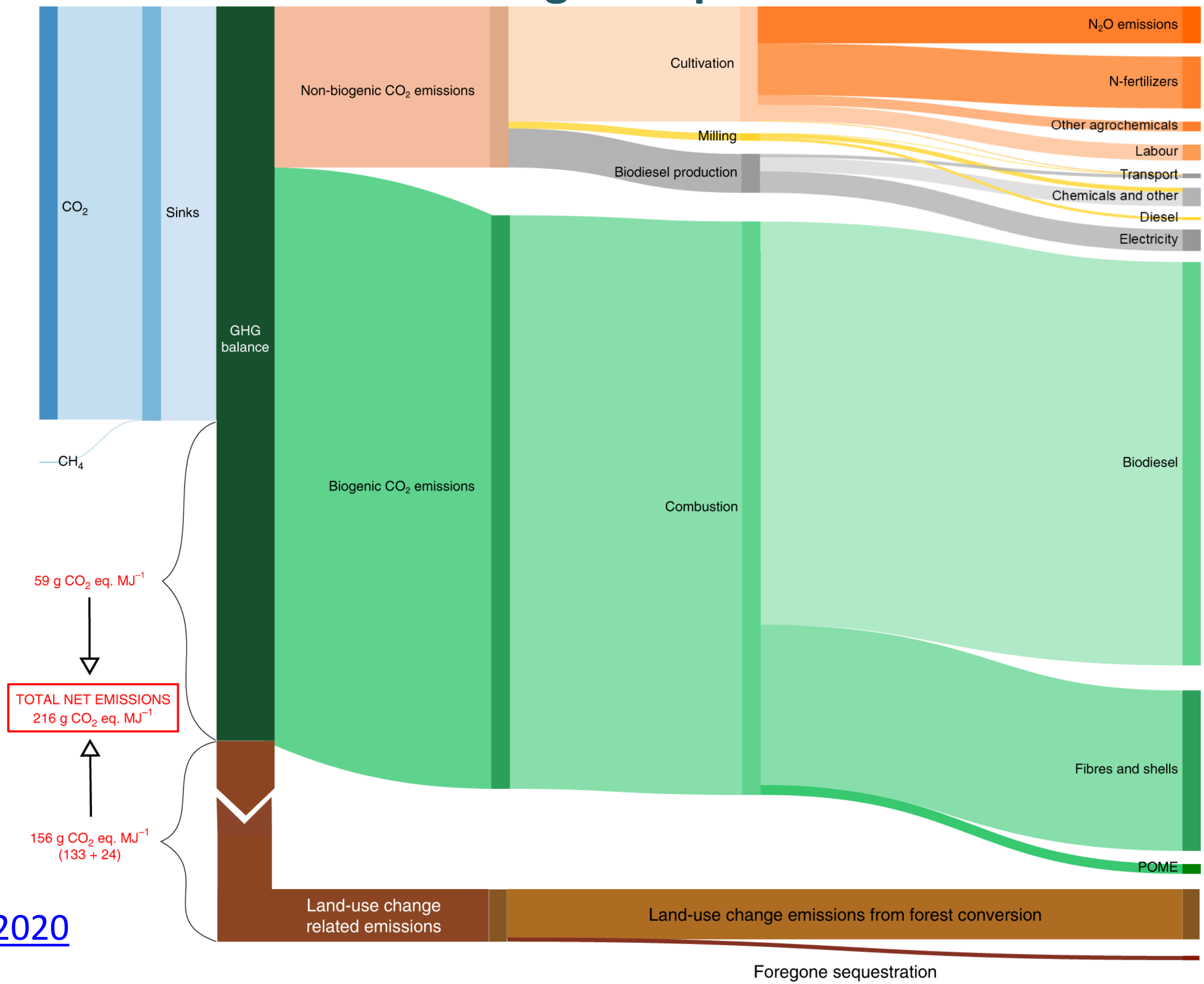
+ Land-use change related emissions (from field data)
+ Foregone sequestration

[Meijide et al., 2020]

Improved LCA shows no GHG savings compared to fossil fuels

Reference fossil fuels: 94 g CO_2-eq. MJ^{-1}

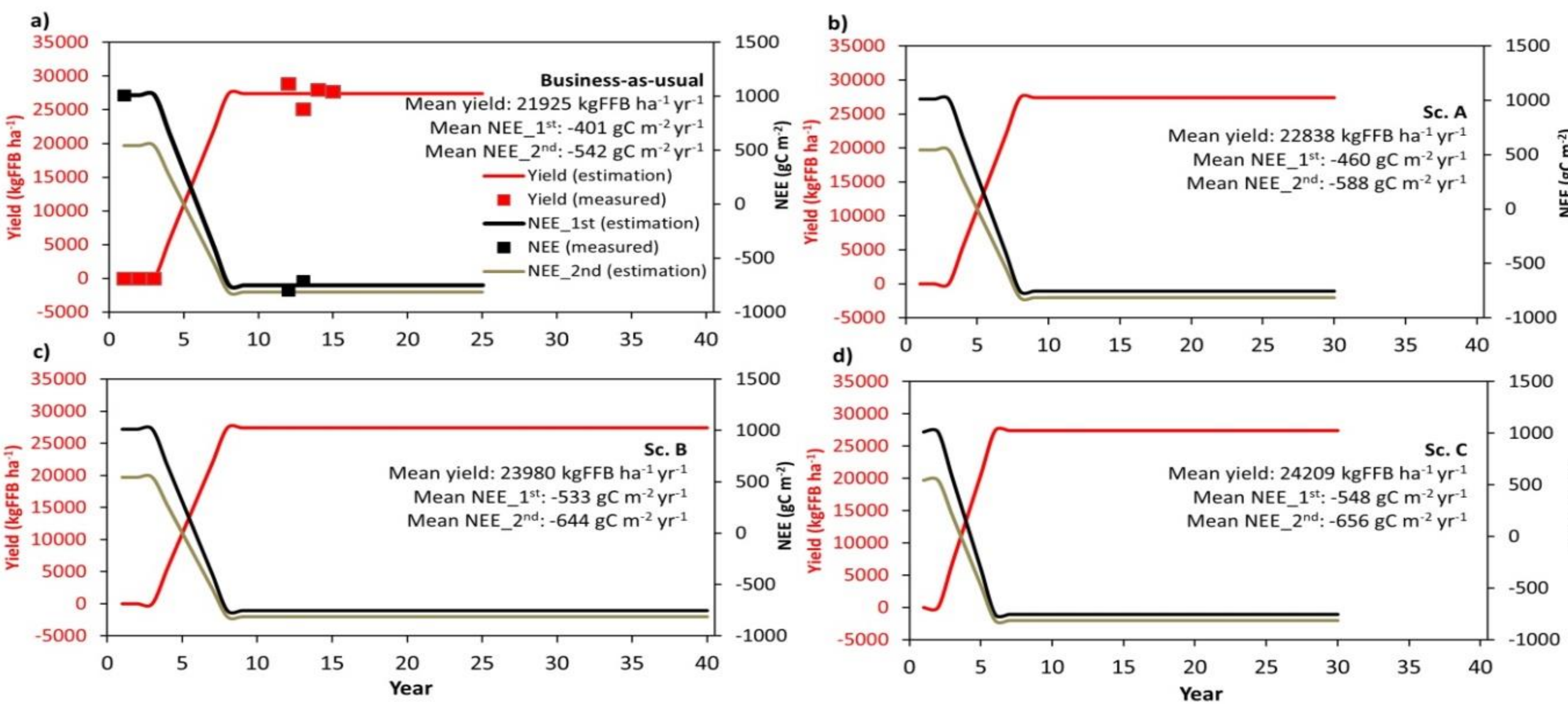
Emissions 129% larger than from reference fossil fuels



[Meijide et al., 2020]

Additional Scenarios which could potentially increase GHG savings

- We developed additional scenarios with longer plantation cycles and early yielding varieties for 1st and 2nd oil palm rotation cycles:
  - Business- as-usual ➔ improved LCA: field data; plantation cycle 25 years
  - Sc. A: field data; plantation cycle 30 years
  - Sc. B: field data; plantation cycle 40 years
  - Sc. C: early yielding variety; plantation cycle 30 years



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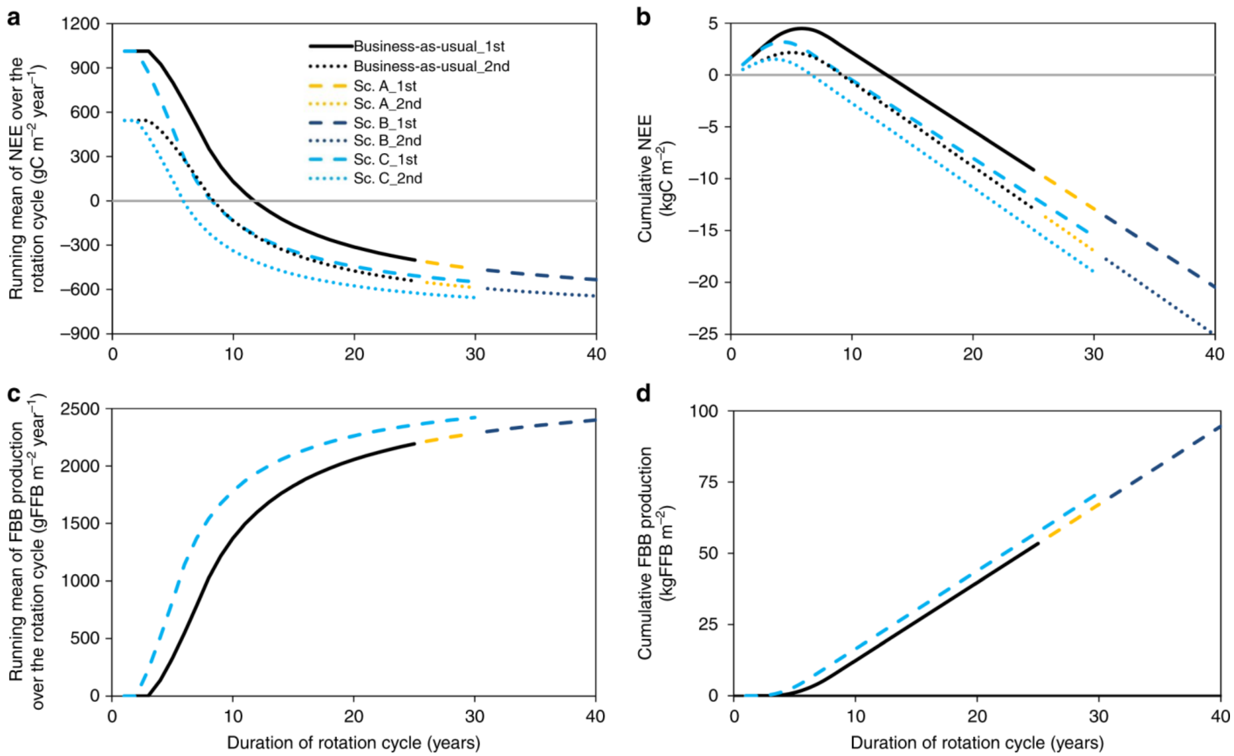
Additional Scenarios which could potentially increase GHG savings

- Net ecosystem CO_2 exchange (NEE) decreases with longer plantation cycles (Sc. A & B) and early yielding varieties (Sc. C)
- NEE decreases in 2[nd] oil palm rotation cycles
- Yield – FFB (fresh fruit bunches) assumed to be the same in 1[st] and 2[nd] oil palm rotation cycles



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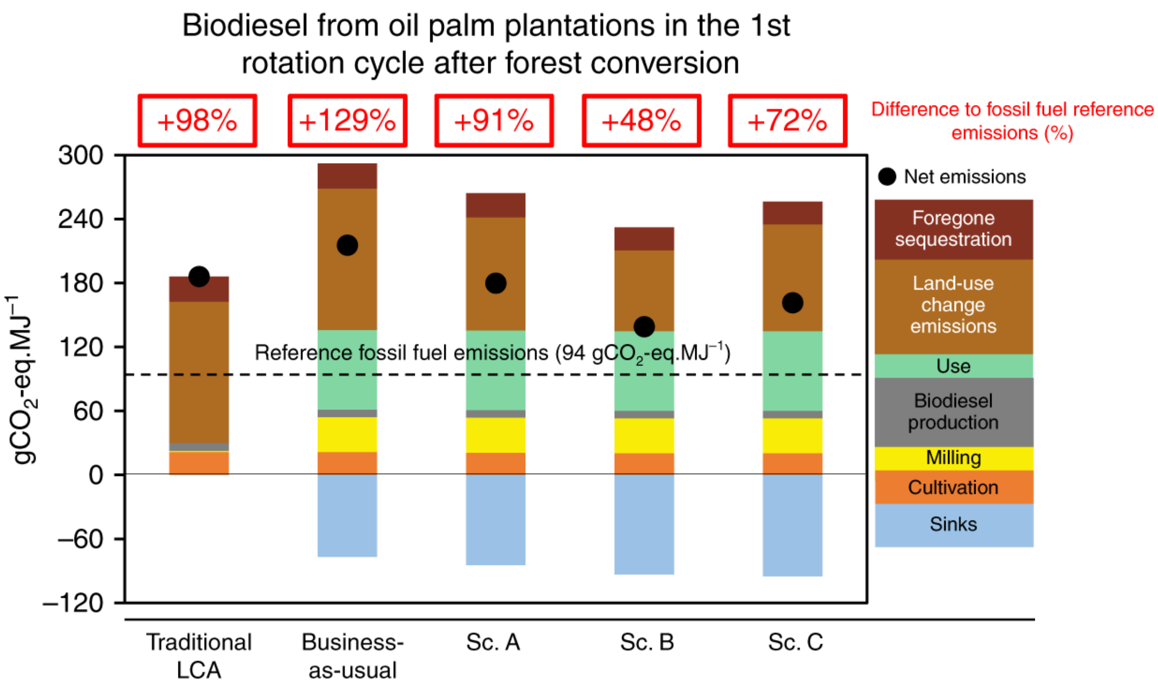
No GHG savings from 1st rotation cycle



Traditional LCA	Business-as-usual	Sc. A	Sc. B	Sc. C	
✔	✔	✔	✔	✔	Land-use change related emissions
✘	✔	✔	✔	✔	Biogenic emissions (improved LCA)
25	25	30	40	30	Rotation cycle (years)
✘	✘	✘	✘	✔	Early yielding
186 (173, 199)	216 (201, 230)	180 (168, 193)	139 (128, 150)	161 (148, 175)	Net emissions (gCO_2-eq.MJ^{-1}) *mean (25, 75-percentile)*

- Emissions from business-as-usual (improved LCA) > Traditional LCA
- No GHG savings from any scenarios ➔ land-use change related emissions are too large to produce emission savings

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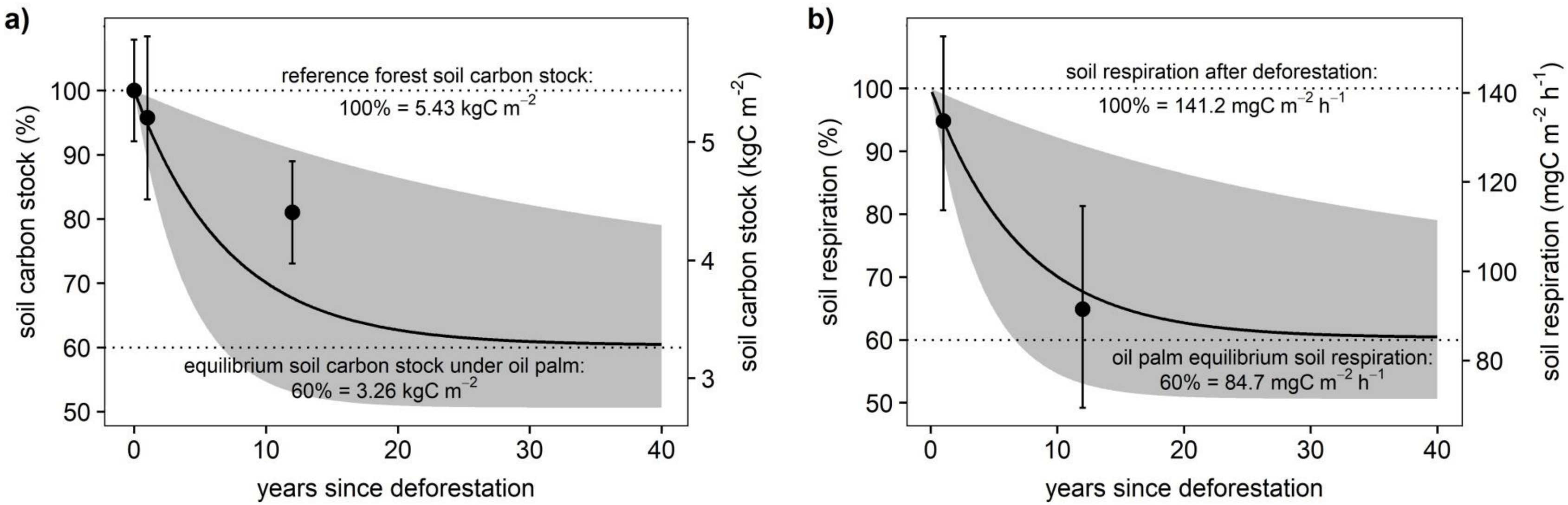
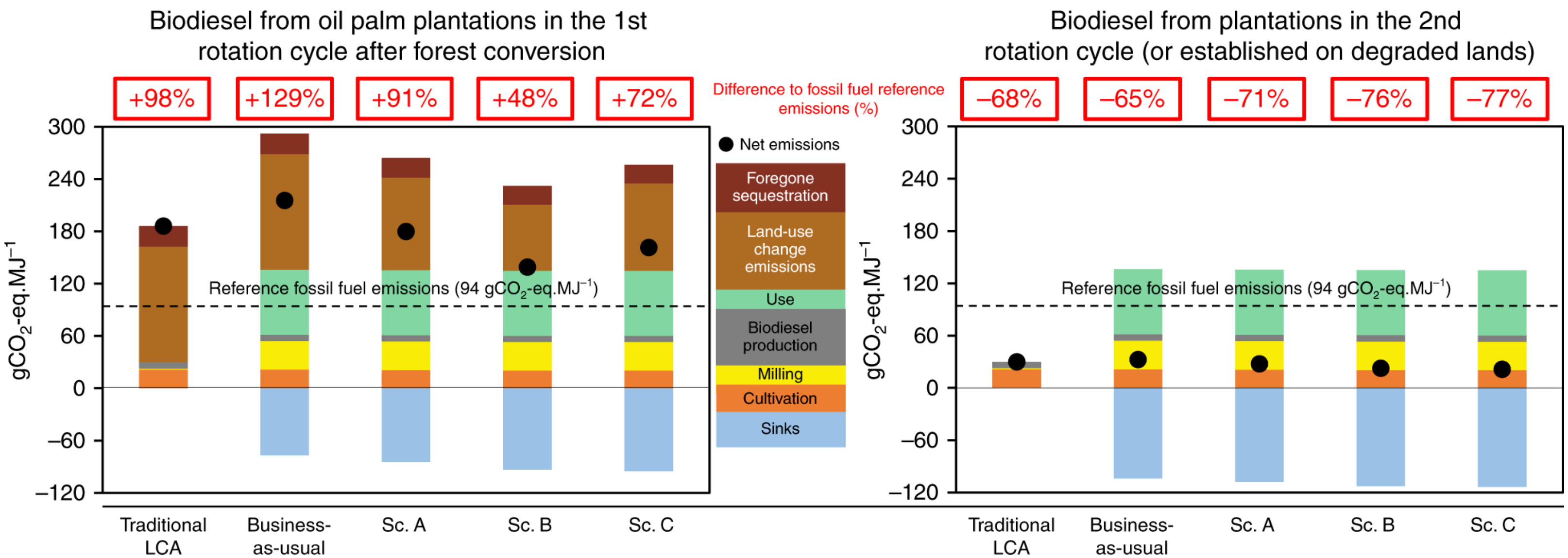
Soil organic decay and soil respiration along plantation life cycle



- Decay of soil C during plantation cycles ➔ we assumed that soil respiration (SR) follows the same decay rate
- Estimation of Net ecosystem exchange (NEE) for 2nd rotation cycles:
  ➔ NEE2nd = NEE1st – SR1st + SR2nd

[Meijide et al., 2020]

GHG savings only possible in 2nd rotation cycles or degraded land



	Traditional LCA	Business-as-usual	Sc. A	Sc. B	Sc. C		Traditional LCA	Business-as-usual	Sc. A	Sc. B	Sc. C
	✔	✔	✔	✔	✔	Land-use change related emissions	✘	✘	✘	✘	✘
	✘	✔	✔	✔	✔	Biogenic emissions (improved LCA)	✘	✔	✔	✔	✔
	25	25	30	40	30	Rotation cycle (years)	25	25	30	40	30
	✘	✘	✘	✘	✔	Early yielding	✘	✘	✘	✘	✔
	186 (173, 199)	216 (201, 230)	180 (168, 193)	139 (128, 150)	161 (148, 175)	Net emissions (gCO_2-eq.MJ^{-1}) *mean (25, 75-percentile)*	30 (27, 32)	33 (23, 44)	28 (18, 38)	23 (12, 36)	21 (9, 34)

- Due to the high emissions associated with forest conversion to oil palm ➔ only biodiesel from second rotation-cycle plantations or plantations established on degraded land has the potential for pronounced GHG emission savings

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- Substantially negative GHG savings from 1st rotation cycles → GHG emissions are much larger than from the reference diesel
- Only possibility for GHG savings is in 2nd rotation cycles or plantations on degraded land
- Possibilities for higher savings with longer plantation cycles, early yielding varieties

  - Higher yielding varieties are being developed → may lead to higher emission savings
- The traditional treatment of the palm-oil milling effluent (POME) will most likely result in higher emissions
- Field-measured data and plantation age should be included in LCAs → C neutrality hypothesis does not comply
- This data could also be valid for other palm-oil products

Thanks for your interest!

Acknowledgements

This study was financed by the Deutsche Forschungsgemeinschaft (DFG, GermanResearch Foundation)—Project-ID 192626868—in the framework of the collaborative German-Indonesian research project CRC990 (subprojects A03, A04 and A05). Special thanks to our field assistants in Indonesia (Basri, Bayu and Darwis) and to Frank Tiedemann, Edgar Tunsch, Dietmar Fellert and Malte Puhan for technical assistance. We thank PTPN VI and the owner of the plantation at Pompa Air for allowing us to conduct our research at their plantation. We would also like to thank the Spanish national project GEISpain (CGL2014-52838-C2-1-R) and the DAAD (scholarship from the programme 'Research Stays for University Academics and Scientist 2018, ref. no. 91687130)' for partly financing A. Meijide during the preparation of this paper.

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Funded by
DFG Deutsche Forschungsgemeinschaft
German Research Foundation

DAAD Deutscher Akademischer Austauschdienst
German Academic Exchange Service