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University of Applied Sciences

Kohlenstoff-Opportunitätskosten und deren Bedeutung für die Klimabewertung von Agrarsystemen

Tagung des Verbandes der Landwirtschaftskammern e. V. (VLK) und des Bundesarbeitskreises Düngung (BAD)

Peter Breunig

24.04.2024

Hintergrund

Applied Sciences for Life

„Wir zeigen, dass auch wenn die Nutzung fossiler Energiequellen sofort beendet werden würde, aktuelle Trends im Agrar- und Ernährungssystem eine Erreichung des 1,5° C-Ziels verhindern und des 2° C-Ziels in Gefahr bringen würden.“

CLIMATE CHANGE

Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets

Michael A. Clark[1*], Nina G. G. Domingo[2], Kimberly Colgan[2], Sumil K. Thakrar[2], David Tilman[3,4], John Lynch[5], Inês L. Azevedo[6,7], Jason D. Hill[2]

The Paris Agreement's goal of limiting the increase in global temperature to 1.5° or 2°C above preindustrial levels requires rapid reductions in greenhouse gas emissions. Although reducing emissions from fossil fuels is essential for meeting this goal, other sources of emissions may also preclude its attainment. We show that even if fossil fuel emissions were immediately halted, current trends in global food systems would prevent the achievement of the 1.5°C target and, by the end of the century, threaten the achievement of the 2°C target. Meeting the 1.5°C target requires rapid and ambitious changes to food systems as well as to all nonfood sectors. The 2°C target could be achieved with less-ambitious changes to food systems, but only if fossil fuel and other nonfood emissions are eliminated soon.

The goal of the Paris Agreement is to limit average global temperature increases above preindustrial levels to "well below 2°C" and to pursue efforts to "limit increase to 1.5°C." Achieving either goal requires large and rapid reductions in greenhouse gas (GHG) emissions (*1*). To date, most efforts have focused on reducing GHG emissions from fossil fuel combustion in electricity production, transportation, and industry. Renewable energy sources, electric vehicles, improved efficiency, and other innovations and behavioral changes could eliminate most of these emissions, and carbon capture and sequestration could reduce atmospheric levels of previously emitted carbon. However, eliminating all emissions from these sectors may not be sufficient to meet the 1.5° and 2°C temperature targets. The global food system is also a major source of GHG emissions, emitting ~30% of the global total (*2*, *3*). Nevertheless, reducing food-related emissions has received less attention, perhaps because these emissions might seem to be an unavoidable environmental cost of feeding humanity.

The global food system generates GHG emissions from multiple sources. Major sources include land clearing and deforestation, which release carbon dioxide (CO_2) and nitrous oxide (N_2O); production and use of fertilizers and other agrichemicals, which emit CO_2, N_2O, and methane (CH_4); enteric fermentation during the production of ruminants (cows, sheep, and goats), which emits CH_4; production of rice in paddies, which emits CH_4; livestock manure, which emits N_2O and CH_4; and combustion of fossil fuels in food production and supply chains, which emits CO_2. In total, global food system emissions averaged ~16 billion tonnes (Gt) CO_2 equivalents $year^{-1}$ from 2012 to 2017 (*4*).

Here, we forecast GHG emissions from the global food system and assess whether they are compatible with the 1.5° and 2°C targets. We forecast emissions as a function of per capita diets (what is eaten and how much), the GHG intensity of various types of foods (emissions per unit of food produced, as estimated through life cycle assessment), and global population size. We assume that food systems continue to transition along trajectories of the past 50 years, which we refer to as business-as-usual (*5*, *6*). This business-as-usual forecast makes straightforward assumptions: (i) per capita dietary composition and calorie consumption continue to change as countries become more affluent (*5*); (ii) crop yields, which influence how much land is converted to cropland, increase along recent trajectories (*5*); (iii) global population increases along the United Nation's medium-fertility pathway (*7*); and (iv) the GHG intensity of foods (*8*) and the rates of food loss and waste (*9*) remain constant through time.

GHG emissions from the global food system largely occur from food production and from land being cleared for food production. Emissions from food production are calculated by pairing life cycle assessment estimates of the GHG emissions per unit of each type of food (*8*) with their forecasted total global demand, and these estimates include emissions from activities such as production of agricultural inputs, fertilizer application, and animal husbandry. Our estimates of emissions from supply chains do not include emissions from transportation, processing, packaging, retail, and preparation, which in total account for a minor fraction (~17%) of total food system emissions (*10*). Emissions from clearing land for food production are estimated by projecting crop yields, combining these with dietary projections to calculate annual rates of agricultural land-cover change, and pairing annual rates of agricultural land-cover change with Intergovernmental Panel on Climate Change (IPCC) Tier 1 estimates of GHG emissions from land clearing or carbon storage in biomass and soil after land abandonment (*11*, *12*).

We next determine the maximum allowable cumulative GHG emissions from all human activities from 2020 onward that are compatible with having a 67 or 50% chance of meeting the 1.5° and 2°C targets, on the basis of the thresholds set in the IPCC Special Report on Global Warming of 1.5°C (*13*). We call these the emissions limits. To accurately incorporate CH_4 into the cumulative emissions framework, we report emissions as global warming potential (GWP*) CO_2 warming-equivalents (CO_2-we) (*14*). We also show results with the more commonly used GWP100 (100-year GWP) metric in data S2. To have a 67% chance of meeting the 1.5° and 2°C targets, the cumulative emissions limits are 500 and 1405 Gt CO_2-we, respectively. For a 50% chance of meeting the targets, the emissions limits are 705 and 1816 Gt CO_2-we, respectively (see supplementary materials).

Our analysis suggests that reducing GHG emissions from the global food system will likely be essential to meeting the 1.5° or 2°C target. Our estimate of cumulative business-as-usual food system emissions from 2020 to 2100 is 1356 Gt CO_2-we (Fig. 1). As such, even if all non–food system GHG emissions were immediately stopped and were net zero from 2020 to 2100, emissions from the food system alone would likely exceed the 1.5°C emissions limit between 2051 and 2063 (date range reflects uncertainties in the 1.5°C emissions limit; see supplementary materials). Further, given our estimate of food system emissions, maintaining a 67% chance of meeting the 2°C target would require keeping cumulative nonfood emissions to <50 Gt CO_2-we in total over the next 80 years. This is slightly more than 1 year of current GHG emissions from non–food system activities (*4*). Maintaining a 50% chance of meeting the 2°C target would allow for 455 Gt CO_2-we in total from nonfood emissions, which is 9 years of current nonfood emissions (*4*). These general trends hold even if emissions from fossil fuel use in the global food system were also to be immediately halted (see supplementary materials).

We next explore how global food system GHG emissions might be reduced through five strategies that target food supply and demand: (i) globally adopting a plant-rich diet [here modeled as a diet rich in plant-based foods that contains moderate amounts of dairy, eggs,

[1]Oxford Martin School and Nuffield Department of Population Health, University of Oxford, Oxford, UK. [2]Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN, USA. [3]Department of Ecology, Evolution, and Behavior, University of Minnesota, St. Paul, MN, USA. [4]Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA. [5]Department of Physics, University of Oxford, Oxford, UK. [6]Department of Energy Resources Engineering, Stanford University, Stanford, CA, USA. [7]Woods Institute for the Environment, Stanford, CA, USA.
*Corresponding author. Email: michael.clark@ndph.ox.ac.uk

Clark et al. 2020

Emissionen des Agrar- & Ernährungssystems

Deutschland

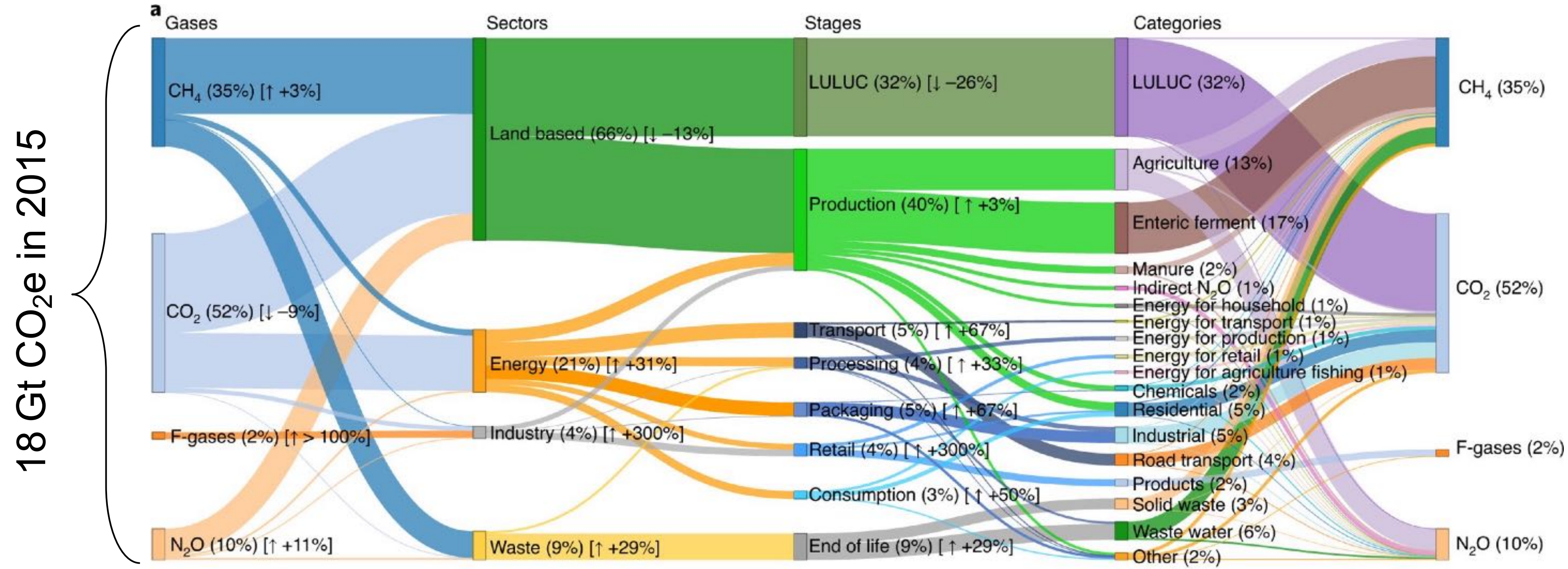
Teilbereich	In Mio. t. CO_2-Äqu.	% Anteil an gesamten THG-Emiss.
Emissionen aus der inländischen Landwirtschaft (Abgrenzung gemäß Klimaschutzgesetz)	68	8,6%
Darunter aus tierischer Verdauung (Methan)	*24*	*3,0%* ← 3.
Darunter landwirtschaftliche Böden (Lachgas)	*25*	*3,2%* ← 2.
Darunter Düngewirtschaft (Methan, Lachgas)	*9*	*1,1%*
Darunter aus stationärer & mobiler Feuerung	*6*	*0,8%*
Emissionen aus landwirtschaftlicher Bodennutzung (Acker- und Grünland, unter LULUCF bilanziert) (insbes. CO_2)	38	4,8% ← 1.
Zwischensumme: Inländische Landwirtschaft und landwirtschaftliche Bodennutzung (2019)	**106**	**13,4%**
Emissionen aus Bereitstellung von Vorleistungen der Landwirtschaft (ohne stationäre & mobile Feuerung) (Schätzung für 2007, Osterburg et al., 2013b)	22	2,8%
Emissionen aus Verarbeitung, Handel, Transport, Verpackung & Zubereitung (privat und Gastronomie) (Schätzung für 2006 (WBAE und WBW, 2016: 29)).	80-128	10,1-16,2%
Summe Agrar- und Ernährungssystem im engeren Sinn	**212-262**	**26,7-33,0%**

Wichtigste Quellen in DE: Moorböden, Lachgas durch Düngung, Wiederkäuer

Grethe et al. 2021

Emissionen des Agrar- & Ernährungssystems

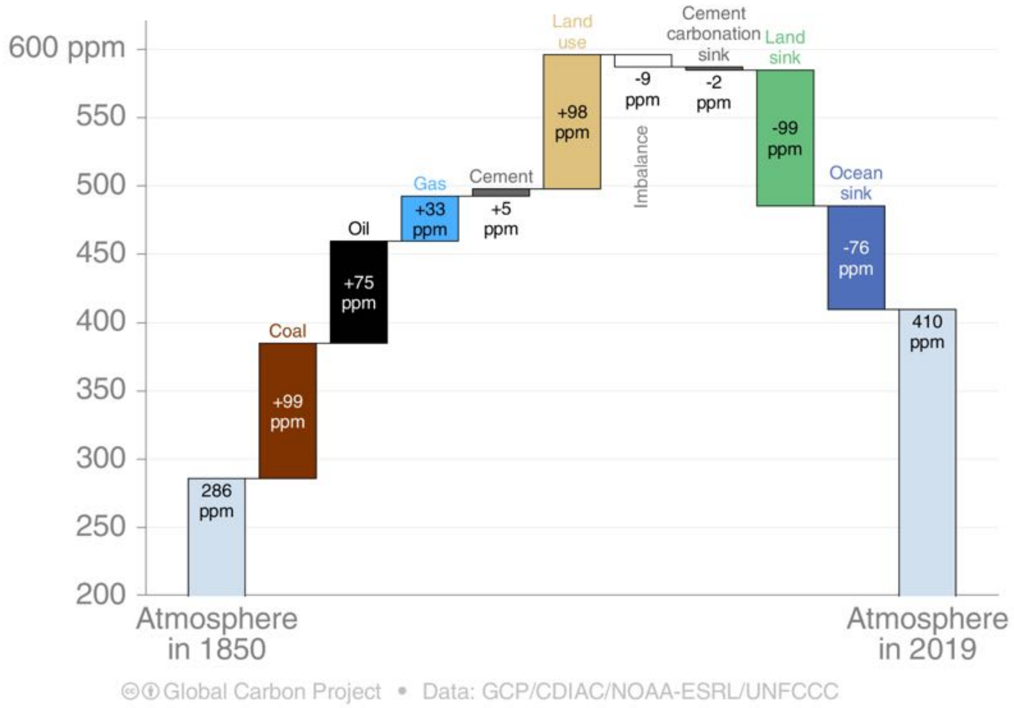
Weltweit



Das globale Agrar- und Ernährungssystem ist für 1/3 aller Emissionen verantwortlich!
Wichtigste Quellen: LULUC, Wiederkäuer, Lachgas durch Düngung und Reisanbau

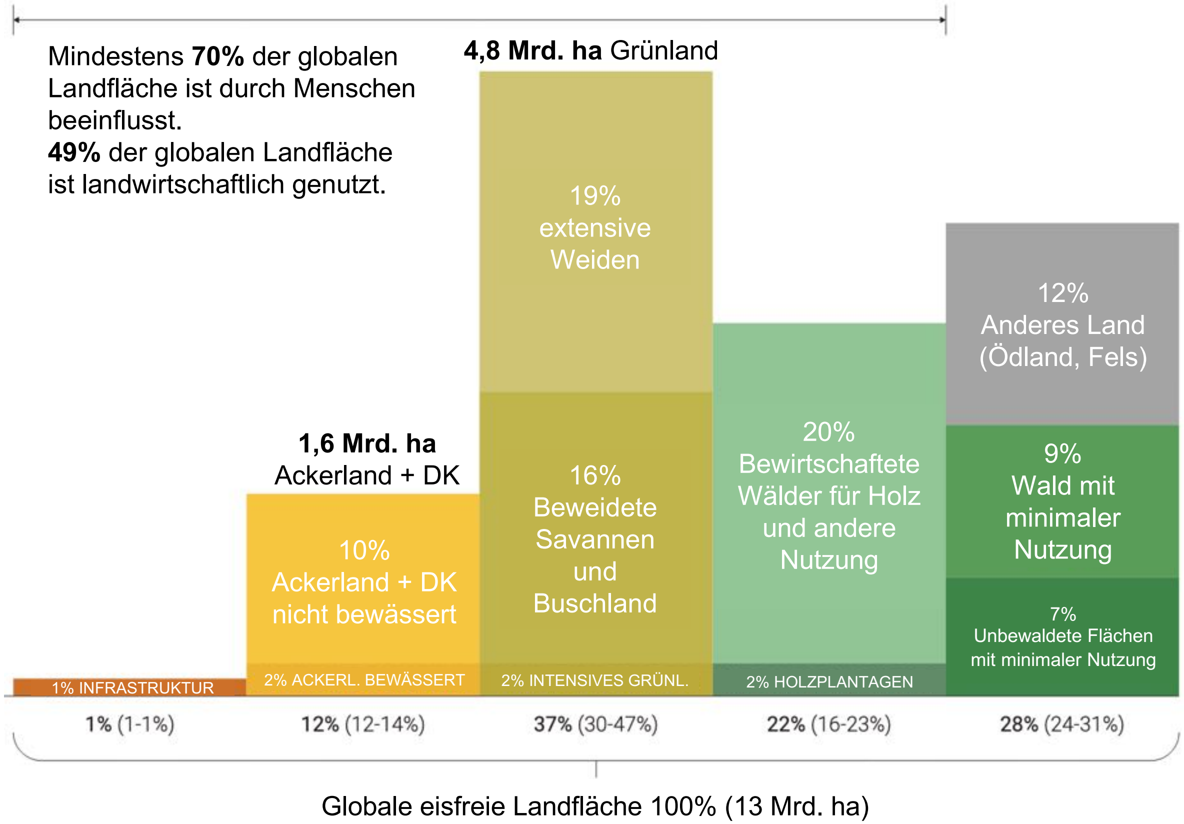
Crippa et al. 2021

Quellen und Senken von CO_2 seit der Industrialisierung



1/3 der CO_2-Emissionen seit 1850 sind auf Landnutzungsänderung zurückzuführen!

Globale Landnutzung heute



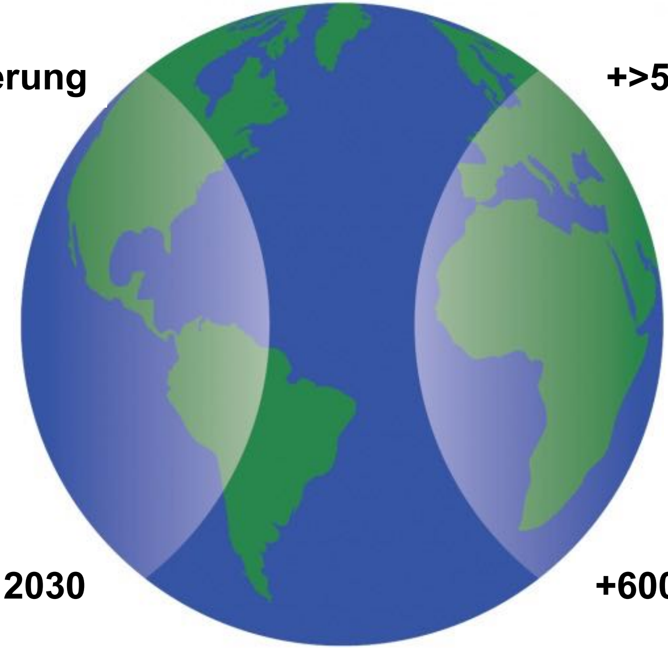
Der globale Druck auf Land bis 2050

+25% Bevölkerung

+45% Bedarf Agrarprodukte

+70% Bedarf Holz

30% unter Naturschutz bis 2030



+>500 Mio. ha Agrarfläche

+80 Mio. ha urbane Flächen

+80 Mio. ha Bioenergie
(BECCS aus NDCs)

+600 Mio. ha Aufforstung (aus NDCs)

WRI, 2022; The Land Gap Report, 2023

Kohlenstoff-Opportunitätskosten

Ökonomie 1 t Weizen

Zahlungsströme	Vollkosten
Saatgut	Saatgut
Dünger	Dünger
Pflanzenschutz	Pflanzenschutz
Betriebsstoffe/Reparaturen	Betriebsstoffe/Reparaturen
Investitionen	**Abschreibungen**
Lohnzahlungen	Lohnzahlungen **+ Lohnansatz**
Pachtzahlungen	Pachtzahlungen **+ Pachtansatz**
	Zinsansatz

Klimawirkung 1 t Weizen

Emissionsströme		Klimakosten
Saatgut		Saatgut
Dünger		Dünger
Pflanzenschutz	**Produktions-emissionen (PEM)**	Pflanzenschutz
Betriebsstoffe		Betriebsstoffe
Maschinen		Maschinen
Ernterückstände		Ernterückstände
C-Veränderung Boden		C-Veränderung Boden
Direkte oder indirekte Landnutzungsänderung		**Kohlenstoff-Opportunitätskosten (COC)**

Ansätze zur Einbeziehung von Landnutzung in die Klimabewertung

- **Direkte Landnutzungsänderung (dLUC)**
  Problem: Stichtagsregelung
- **Indirekte Landnutzungsänderung (iLUC)**
  Problem: Ökonomische Modelle führen per se nicht zu effizienten Lösungen

Problem: Speicherpotenzial länger genutzter Flächen wird nicht berücksichtigt

- **Kohlenstoff-Opportunitätskosten (COC)**

Kohlenstoff-Opportunitätskosten (COC)

- Bei jeder Nutzung einer Fläche entgeht C-Speicherleistung der natürlichen Vegetation
- Wird dieser entgangene Nutzen nicht berücksichtigt, kommt es zu einer aus Klimaschutzsicht ineffizienten Verwendung der knappen Fläche auf unserer Erde
- Die entgangene Speicherleistung der natürlichen Vegetation ist größer als die Produktionsemissionen eines Produkts

LETTER

Corrected: Publisher Correction

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Assessing the efficiency of changes in land use for mitigating climate change

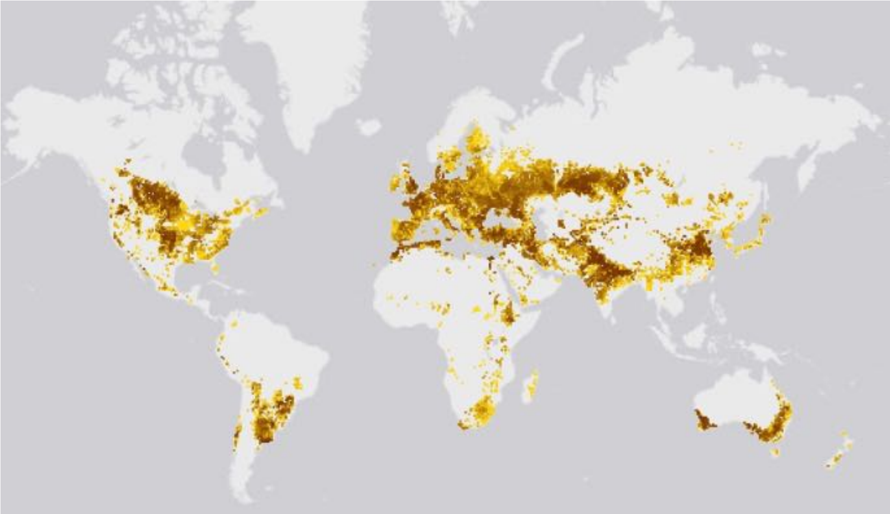
Timothy D. Searchinger[1,2]*, Stefan Wirsenius[3], Tim Beringer[4] & Patrice Dumas[5,6]

Land-use changes are critical for climate policy because native vegetation and soils store abundant carbon and their losses from agricultural expansion, together with emissions from agricultural production, contribute about 20 to 25 per cent of greenhouse gas emissions[1,2]. Most climate strategies require maintaining or increasing land-based carbon[3] while meeting food demands, which are expected to grow by more than 50 per cent by 2050[1,2,4]. A finite global land area implies that fulfilling these strategies requires increasing global land-use efficiency of both storing carbon and producing food. Yet measuring the efficiency of land-use changes from the perspective of greenhouse gas emissions is challenging, particularly when land outputs change, for example, from one food to another or from food to carbon storage in forests. Intuitively, if a hectare of land produces maize well and forest poorly, maize should be the more efficient use of land, and vice versa. However, quantifying this difference and the yields at which the balance changes requires a common metric that factors in different outputs, emissions from different agricultural inputs (such as fertilizer) and the different productive potentials of land due to physical factors such as rainfall or soils. Here we propose a carbon benefits index that measures how changes in the output types, output quantities and production processes of a hectare of land contribute to the global capacity to store carbon and to reduce total greenhouse gas emissions. This index does not evaluate biodiversity or other ecosystem values, which must be analysed separately. We apply the index to a range of land-use and consumption choices relevant to climate policy, such as reforesting pastures, biofuel production and diet changes. We find that these choices can have much greater implications for the climate than previously understood because standard methods for evaluating the effects of land use[4–11] on greenhouse gas emissions systematically underestimate the opportunity of land to store carbon if it is not used for agriculture.

Kohlenstoff-Opportunitätskosten (COC)

Wieviel Kohlenstoffbindung entspricht 1 t Weizen?

Weizenanbaufläche weltweit



- Fläche erzeugt:
  750 Mio. t Weizen pro Jahr
- C-Speicherpotential der Fläche bei natürlicher Vegetation (Wald):
  1,4 Mrd. t CO_2 pro Jahr
- Kohlenstoff-Opportunitätskosten (COC) bei Weizen:
  1,9 t CO_2 / t Weizen

MapSPAM, Berechnung nach Searchinger et al. 2018

Kohlenstoff-Opportunitätskosten (COC)

Table 1 | COCs and global PEMs of major crop and livestock products

	COC[a] (kg CO_2 per kg fresh weight)	PEMs (kg CO_2e per kg fresh weight)	Total (kg CO_2e per kg fresh weight)	Total (g CO_2e per kcal[c])	Total (kg CO_2e per kg protein)
Maize	2.1	0.46	2.6	0.82	29
Rice (rough)	2.6	2.17	4.8	2.0	69
Wheat	1.9	0.69	2.6	0.9	23
Cassava	1.7	0.04	1.7	1.6	160
Potato	0.6	0.09	0.7	1.1	38
Soybeans	5.9	0.26	6.1	1.5	17
Pulses	10.5	0.55	11	3.1	47
Vegetable oils	9.7	1.3	11	1.2	Not applicable
Beef[b]	144	44	188	102	1,250
Cow milk	6.2	2.3	8.4	13.1	260
Pork	14	5.5	20	9.4	150
Poultry meat	11	3.7	14	8.4	110

Values are calculated using the carbon loss method and 4% time discounting.
[a]Includes peatland emissions.
[b]Average, including meat from dairy animals.
[c]1 kcal = 4,184 J.

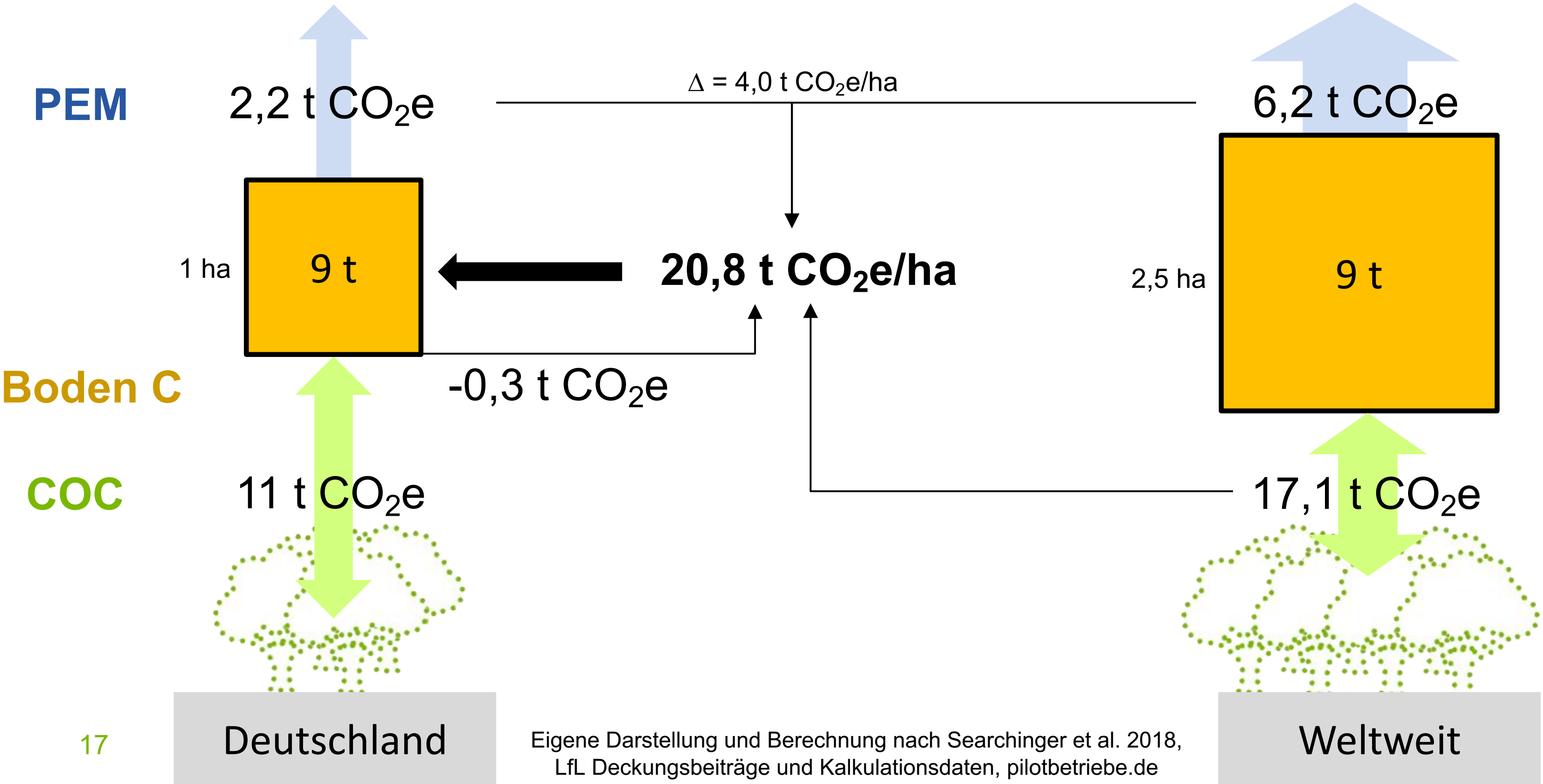
Searchinger et al. 2018

COC zukünftig auch Teil des GHG Protocols

Table 7.1 Overview of metrics related to land use change

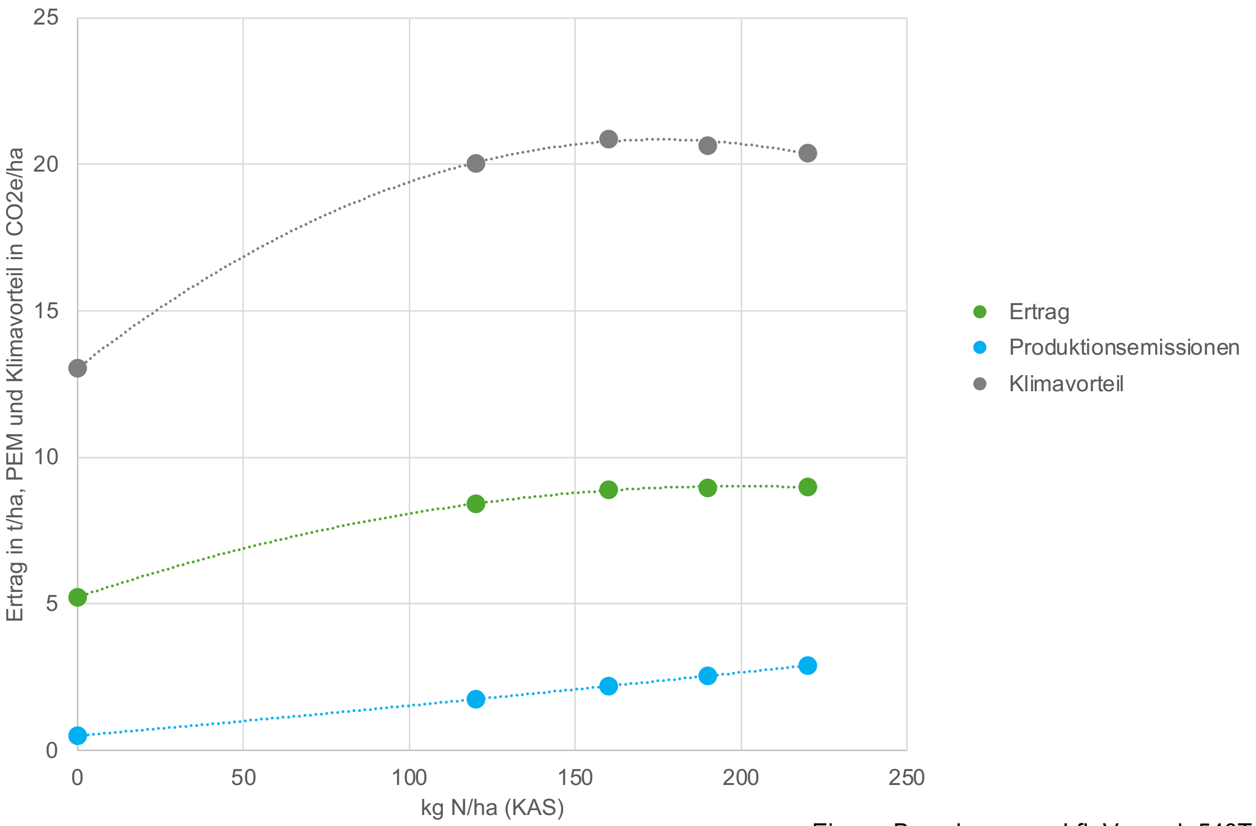
Metric	Definition	Unit of Measure	Scope(s) and relevant section
Direct land use change (dLUC) emissions	Emissions (primarily from carbon stock losses) due to recent (previous 20 years or more) land conversion directly on the area of land that a company owns/controls or on specific lands in the company's value chain	CO_2e	Scope 1, scope 2, and scope 3 emissions; see section 7.2
Statistical land use change (sLUC) emissions	Emissions (primarily from carbon stock losses) due to recent (previous 20 years or more) land conversion within a landscape or jurisdiction. sLUC can serve as a proxy for dLUC where specific sourcing lands are unknown or when there is no information on the previous states of the sourcing lands	CO_2e	
Indirect land use change (iLUC) emissions	Emissions (primarily from carbon stock losses) due to land conversion on lands not owned or controlled by the company, or in its value chain, induced by change in demand for (or supply of) products produced or sourced by the company	CO_2e	Scope 1, scope 2, and scope 3 land tracking; see section 7.3
Carbon opportunity costs (COC)	Emissions from total historical carbon losses from plants and soils on lands productively used (this quantity also represents the amount of carbon that could be stored if land in production were allowed to return to native vegetation)	CO_2e	
Land occupation	The amount of land occupied for a certain time to produce a product	hectares	

Klimavorteil von 1 ha Weizen in DE



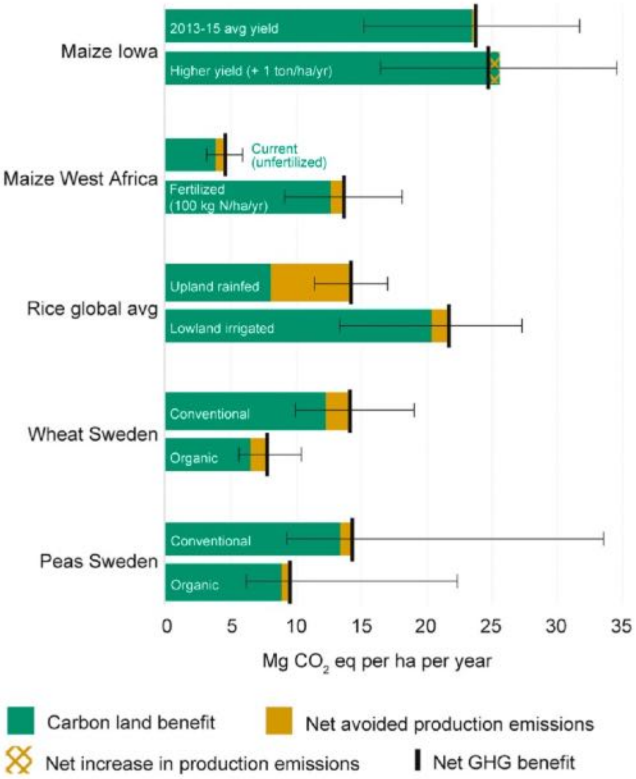
Eigene Darstellung und Berechnung nach Searchinger et al. 2018, LfL Deckungsbeiträge und Kalkulationsdaten, pilotbetriebe.de

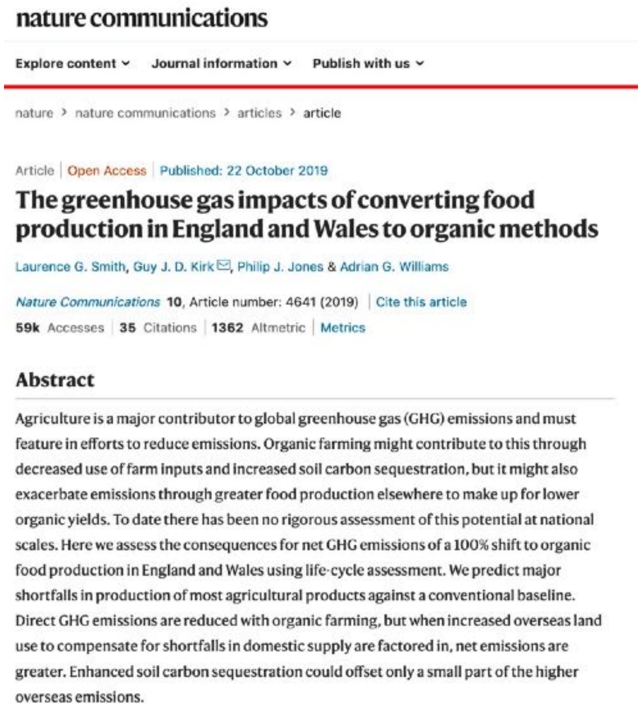
Klimavorteil durch N-Düngung – Bsp. Weizen



Eigene Berechnungen, LfL Versuch 540T, Searchinger et al. 2018

Ertrag = Klimaschutz





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Article | Open Access | Published: 22 October 2019

The greenhouse gas impacts of converting food production in England and Wales to organic methods

Laurence G. Smith, Guy J. D. Kirk, Philip J. Jones & Adrian G. Williams

Nature Communications **10**, Article number: 4641 (2019) | Cite this article

59k Accesses | **35** Citations | **1362** Altmetric | Metrics

Abstract

Agriculture is a major contributor to global greenhouse gas (GHG) emissions and must feature in efforts to reduce emissions. Organic farming might contribute to this through decreased use of farm inputs and increased soil carbon sequestration, but it might also exacerbate emissions through greater food production elsewhere to make up for lower organic yields. To date there has been no rigorous assessment of this potential at national scales. Here we assess the consequences for net GHG emissions of a 100% shift to organic food production in England and Wales using life-cycle assessment. We predict major shortfalls in production of most agricultural products against a conventional baseline. Direct GHG emissions are reduced with organic farming, but when increased overseas land use to compensate for shortfalls in domestic supply are factored in, net emissions are greater. Enhanced soil carbon sequestration could offset only a small part of the higher overseas emissions.

Emissionen steigen um 21% trotz höherer C-Sequestrierung im Ökolandbau

Trends in Plant Science

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Special issue: Climate change and sustainability I

Forum

Genetically modified crops support climate change mitigation

Emma Kovak, Dan Blaustein-Rejto and Matin Qaim

Genetically modified (GM) crops can help reduce agricultural greenhouse gas (GHG) emissions. In addition to possible decreases in production emissions, GM yield gains also mitigate land-use change and related emissions. Wider adoption of already-existing GM crops in Europe could result in a reduction equivalent to 7.5% of the total agricultural GHG emissions of Europe.

EU-Agrar-Emissionen würden durch GVO um 7,5% sinken

Searchinger et al. 2018; Smith et al. 2019; Kovak et al. 2021

Klimawirkung von Zwischenfrüchten vor Mais

	EU27 Average per ha t CO_2e/ha
Carbon Land Benefit based on Yield Gain	**1,46**
Carbon Sequestration	1,43
Carbon Benefit based on Nitrogen Fertilizer Savings	1,03
Reduced N_2O Emissions due to less Leaching	0,10
Albedo change	0,20
Total Climate Benefit	**4,23**
N_2O Emissions	0,04
Foregone Net GHG Benefit of Wheat due to CC Seed Land Requirements	0,28
Production Emissions Catch Crop Seed	0,39
Processing, Packaging and Transport of Catch Crop Seed	0,08
Additonal Machinery Operations	0,14
Total Climate Cost	**0,93**
Net Climate Change Mitigation Impact of Cover Crops	**3,30**

Schön, Gentsch und Breunig 2024 (Veröffentlichung: Mai 2024 in PLOS ONE)

Abwägung Flächennutzung

	Klimavorteil t CO_2e/ha & Jahr
a) GLÖZ 8 Stilllegung	2
b) Biokraftstoffe in DE (inkl. Koppelprodukte)	7
c) Biogas mit Silomais (inkl. 1/3 Wärmenutzung)	8
d) Aufforstung / Hecken	11
e) Weizen (9 t/ha)	21
f) Milch von Grünland (4.000 kg ECM/ha)	29
g) Wiedervernässung von Moorflächen	35
h) Freiflächen PV	>300*
i) Windenergie	>10.000*
j) Biogas & Biokraftstoffe aus Gülle/Reststoffen	Keine Flächenkonkurrenz
k) PV auf Dächern und Parkplätzen	
l) Humusaufbau	

*Klimavorteil sinkt wenn EE-Anteil im Strommix steigt

Fehrenbach, Bürck 2022; Fachverband BIOGAS, 2023; Searchinger et al. 2018; Grethe et al. 2021; Wirth, 2022

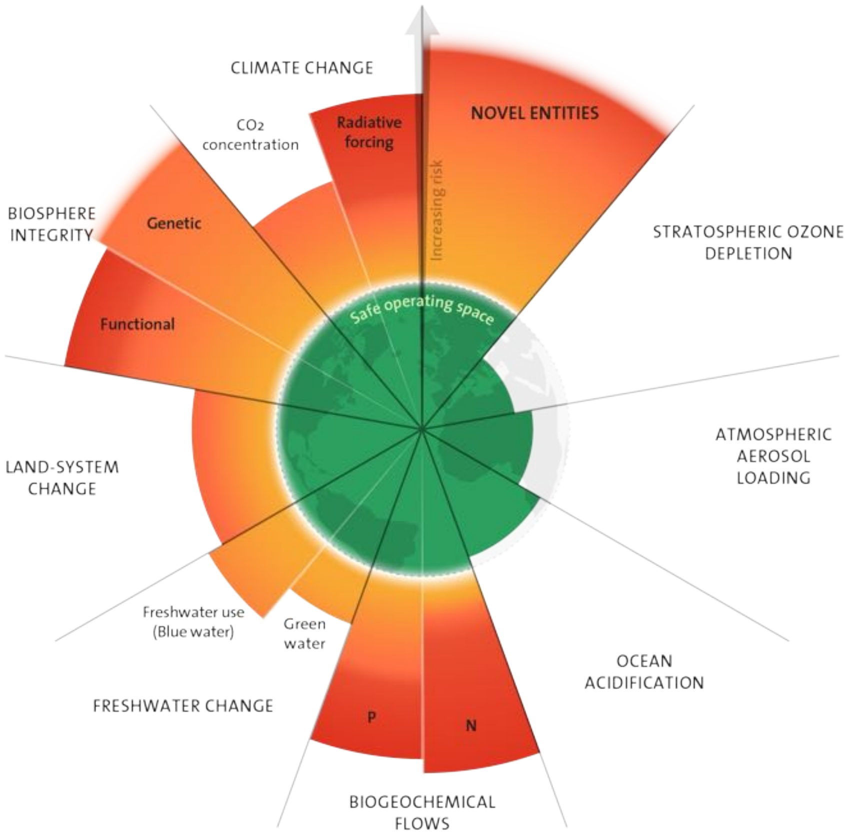
Aber…

Applied Sciences for Life

Aber…

1. Nachhaltigkeit ist mehr als Klimaschutz
2. Rebound-Effekte der Ertragssteigerung

Nachhaltigkeit ist mehr als Klimaschutz



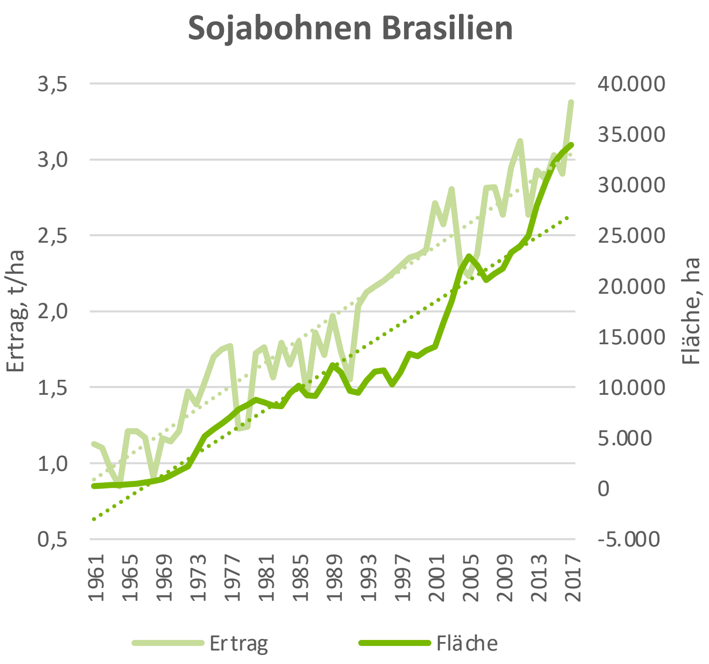
Richardson et al. 2023

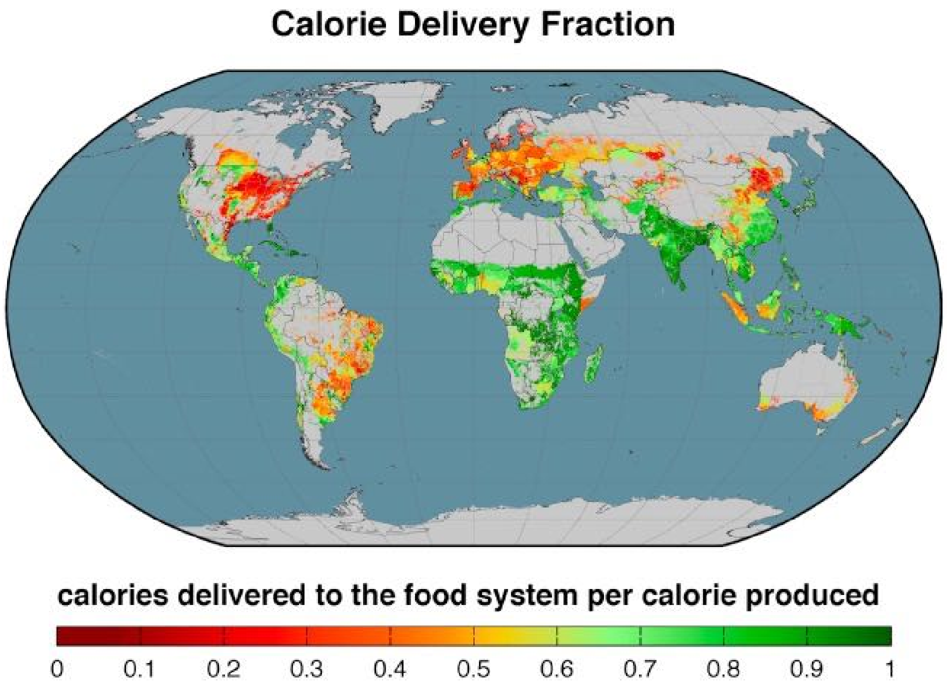
Nachhaltigkeit ist mehr als Klimaschutz

Ansatz: Minimumanforderungen erfüllen und Win-Win-Optionen bei hohen & stabilen Erträgen umsetzen

- Hohe Erträge mit mind. 20% naturnahen Flächen in der Landschaft verbinden (Tscharntke et al. 2021)
- Räumliche, zeitliche und biologische Diversität von Agrarsystemen erhöhen (Rasmussen et al. 2024)
- Input-Effizienz weiter steigern, insbesondere bei N und PSM (Gu et al. 2023)
- Low-Impact-Inputs: Green Ammonia N-Dünger etc.

Rebound-Effekte der Ertragssteigerung



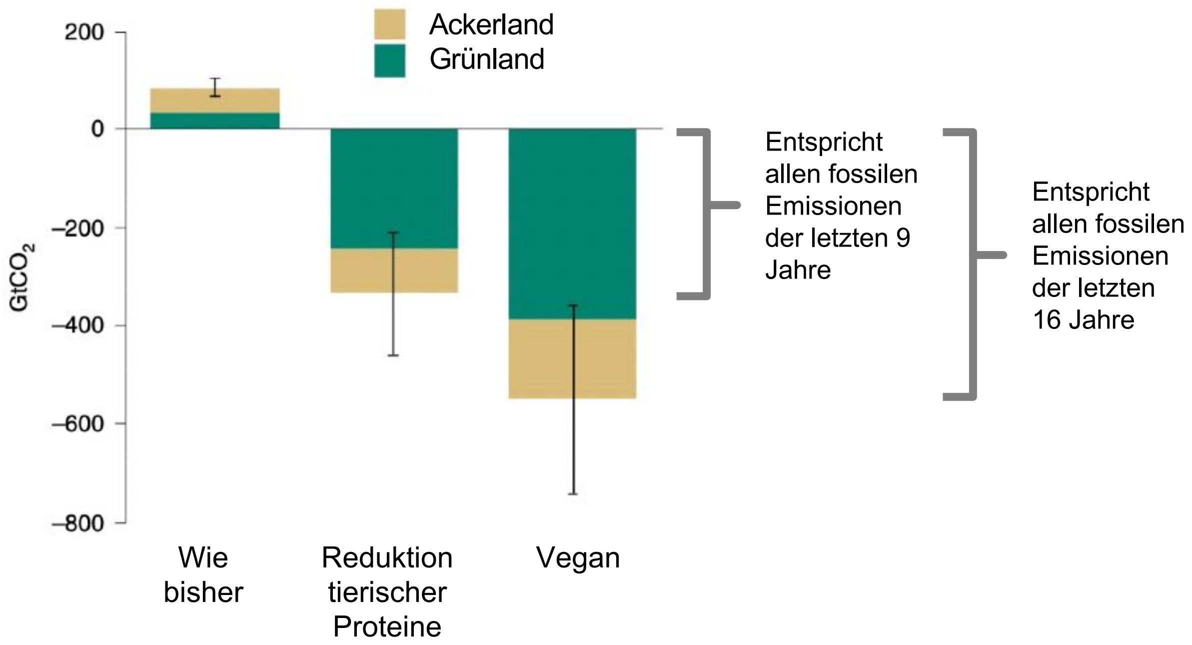


Eigene Darstellung nach FAOSTAT, Cassidy et al. 2013

Rebound-Effekte der Ertragssteigerung

- Schutz von natürlicher Vegetation muss global an Bedeutung gewinnen
- Flächeneffiziente Erzeugung braucht **flächeneffiziente Nachfrage**:
  - Stärker pflanzenbasierte Ernährung (Hayek et al. 2021)
  - Weniger Verluste
  - Reduktion der energetischen Nutzung von Anbaubiomasse (Searchinger et al 2018)
- Forschung zur Integration von COC in Marktmodellierung

Flächeneffiziente Nachfrage durch stärker pflanzenbasierte Ernährung



Hayek et al. 2021

Zusammenfassung

Applied Sciences for Life

Zusammenfassung

- Flächennutzung ist der größte Treiber der Klimawirkung des globalen Agrar- und Ernährungssystems
- Bisherige THG-Bilanzierungsansätze betrachten die Flächennutzung unzureichend – COC bieten einen universellen Ansatz
- Durch Einbeziehung von COC wird der Ertrag einer Fläche als positive Klimawirkung durch Flächeneinsparung sichtbar
- Dies ist die zweitbeste Lösung, um die knappe Fläche klimaeffizient zu nutzen (nach einem globalen CO_2-Preis)
- Die Einbeziehung von COC entbindet aber nicht von einer Abwägung zwischen anderen Nachhaltigkeitsdimensionen und Rebound-Effekte müssen betrachtet werden

Danke.