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DEVELOPING CONSUMPTION-BASED EMISSIONS INDICATORS FROM AGRICULTURE, FORESTRY AND LAND-USE (AFOLU)

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Developing Consumption-Based Emissions Indicators From Agriculture, Forestry and Land-use (AFOLU) Activities

Grégoire Garsous

Understanding consumption-based emissions from Agriculture, Forestry and Land-use (AFOLU) activities is important in developing climate policy for the sector. This paper proposes a new methodology to construct indicators – CBAFOLU indicators – to provide estimates of greenhouse gas (GHG) emissions arising from AFOLU activities (including fisheries) in the global supply chain of finished products. The CBAFOLU indicators identify the countries where emissions are generated and the countries where the goods that "embody" these emissions are eventually consumed. CBAFOLU indicators are provided for bilateral flows of emissions for 65 countries over 2005-15. The indicators also break down emissions by types of GHG: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and CO2 emissions from land use, land-use change, and forestry (LULUCF). Given their preliminary nature, the CBAFOLU indicators should be seen as a first building block in a series of steps to explore the allocation of AFOLU activities across countries through the lens of sustainability; priorities for further work to refine the indicators are also proposed.

Key words: Climate change, trade, environmental policies

JEL Codes: F18, O13, Q15, Q17, Q54

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Key messages

- This paper proposes a methodology to construct preliminary indicators of consumption-based emissions from AFOLU activities – the CBAFOLU indicators.
- These indicators provide estimates of GHG emissions arising from AFOLU activities in the global supply chains of finished products.
- The CBAFOLU indicators identify the countries where emissions are generated and the countries where the goods that "embody" these emissions are eventually consumed – providing bilateral flows of emissions for 65 countries over the timeline 2005-15.
- The indicators also break down emissions by type of greenhouse gas: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and CO_2 emissions from land use, land-use change, and forestry (LULUCF).

1. Introduction

Agriculture, forestry, and land-use (AFOLU) activities account for approximately 23% of global anthropogenic greenhouse gases (GHG) emissions, being the second largest sector contributing to total GHG emissions after electricity and heat production (Blandford and Hassapoyannes, 2018[1]). Agriculture contributes to GHG emissions by emitting methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) through a wide range of activities, including livestock production; rice cultivation; crop production relying on the use of synthetic and organic fertilisers; and on-farm energy use. In addition, forestry, other land uses and land-use changes like afforestation and deforestation (forest conversion) – which are closely linked to agricultural expansion[1] – may cause emissions and removals on forest land, and in the soil of cropland, grassland, and wetlands. Human activity can also cause methane emissions from wetlands exploitation.

The AFOLU sector is also one of the most vulnerable to global warming. Climate change has already severely affected AFOLU activities through increased forest fires; increased frequency and intensity of droughts in some regions; increased intensity of heavy precipitation at the global level; contributing to desertification in some areas; the expansion of arid zones; and contraction of polar climate zones (IPCC, 2019[2]). In addition, climate change can exacerbate land degradation through increased rainfall intensity, flooding, and heat stress among others (OECD, 2014[3]). Food security concerns arise from such prospects (Ignaciuk and Mason-D'Croz, 2014[4]). Already, significant crop yield declines (e.g. maize and wheat) have been observed in some low-latitude regions.

In line with their pledges under the Paris Climate Agreement, an increasing number of countries are contemplating the implementation of ambitious domestic climate policies, which may target reduction of GHG emissions from the AFOLU sector. However, in an international setting where countries take actions to address climate change in a non-coordinated fashion, concerns have been raised over a non-optimal reallocation of AFOLU activities to countries with currently higher emissions intensities.

For a wide variety of goods, AFOLU activities are upstream in the production stage. Therefore, GHG emissions associated with AFOLU activities should be considered "embodied" in these products, which may cross many borders before reaching their final consumers. For instance, durum wheat produced in Canada may be processed in Italy to make pasta for lasagnes served in a German restaurant. The global value chains (GVC) of food products – to which the AFOLU sector contributes a large share of total value added – are complex and involve the participation of many industries worldwide (Greenville, Kawasaki and Beaujeu, 2017[5]). In such an interconnected world, monitoring cross-border flows of GHG emissions and

[1] Agricultural activities are estimated to account for at least 90% of emissions due to land-use change (Bennetzen, Smith and Porter, 2016[18]).

tracing them back their origin from their final destination are necessary building blocks for a better understanding of the distribution of AFOLU emissions across the global economy.

The OECD has already made contributions in this area by estimating the consumption-based CO_2 emissions from fuel combustion (Yamano and Guilhoto, 2020[6]; Wiebe and Yamano, 2016[7]). This paper builds on this expertise and proposes a methodology to construct preliminary indicators on consumption-based emissions from AFOLU activities – the CBAFOLU indicators. These indicators provide estimates of GHG emissions arising from AFOLU activities (including fisheries)[2] in the global supply chain of finished products.[3] The CBAFOLU indicators identify the countries where emissions are generated and the countries where the goods that "embody" these emissions are eventually consumed. The CBAFOLU indicators provide such bilateral flows of emissions for 65 countries over the timeline 2005-15. The indicators also break down emissions by types of greenhouse gas: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and CO_2 emissions from land use, land-use change, and forestry (LULUCF).[4]

The methodology presented in this paper combines a number of publicly available databases: the OECD Air Emissions Accounts (AEAs), which report data on GHG emissions following the System of Environmental-Economic Accounting (SEEA) Central Framework; the United Nation Framework on Climate Change Convention (UNFCCC) GHG inventory database; the FAOSTAT database on emissions from agriculture; and the IEA dataset on CO_2 emissions from fuel combustion. The methodologies of these data sources vary and those relying on robust estimations are prioritised over databases compiled with more basic approaches.

Given their preliminary nature, the CBAFOLU indicators have some limitations. First, they provide only a "snapshot" of the origins and destinations of the current AFOLU emissions flows. Therefore, from an environmental perspective, they provide no indication as to how well AFOLU activities are allocated across countries. Second, the CBAFOLU indicators focus on current emissions *flows* and do not account for emissions *stocks* – i.e. the total net cumulative emissions of countries over a given time period. Finally, the CBAFOLU indicators aggregate AFOLU activities into one single sector, the composition of which may vary across countries. As a result, the indicators do not account for cross-country differences in emissions intensities due to cross-country differences in the composition of AFOLU activities. This again poses a limitation in terms of policy implications with respect to how different activities could be optimally allocated globally.

Thus, the CBAFOLU indicators should be considered as a first building block in a series of steps that explore the allocation of AFOLU activities across countries through the lens of sustainability. In order to develop policy guidance, further work would be needed to refine the indicators – e.g. making them more granular by breaking down AFOLU activities into subsectors.

The rest of this paper is organised as follows. Section 2 presents the methodology used to construct the CBAFOLU indicators. Section 3 concludes by outlining future improvements that can be brought to the CBAFOLU indicators.

[2] Because it follows the OECD Inter-Country Input-Output classification of economic activities, the CBAFOLU indicators also cover energy-related GHG emissions in fisheries. Therefore, the definition of AFOLU activities in this paper will also cover fisheries.

[3] In addition to AFOLU activities, the supply chain of finished food products generally includes upstream production of fertilisers, processing, transportation, and waste, which are considered separate activities and are not covered by the CBAFOLU indicators. However, indicators on CO_2 emissions from fuel combustion associated with these production stages are available on OECD.Stat. See (Wiebe and Yamano, 2016[7]) and (Yamano and Guilhoto, 2020[6]).

[4] The database will be provided to policy makers (on request) and will provide a breakdown of emissions by types of gases (CO_2, CH_4, N_2O, and LULUCF). Therefore, such breakdown will enable analysts to treat LULUCF emissions separately in their analytical works.

2. Methodology

2.1. Decomposing the global value chains with the OECD Inter-Country Input-Output framework

The estimation of consumption-based emissions requires the decomposition of the global value chains (GVCs) to identify production stages of goods and the countries where they are eventually consumed. The OECD Inter-Country Input-Output (ICIO) framework makes use of global input-output matrices and final demand vectors to decompose GVCs.[5] Introducing emissions data into this decomposition algorithm allows for the mapping of emissions onto their associated production segment and to identify where these emissions were generated along the GVC until final consumption of the goods that embody them.[6] In other words, this process pins down the location and the amount of emissions associated with the final consumption of goods in all sectors and all countries covered by the OECD ICIO framework. The OECD ICIO coverage of sectors and countries can be found in Annex B.

Conducting such an exercise with AFOLU emissions rests on the assumption that they are eventually consumed through goods. This assumption is reasonable for direct agricultural emissions – which directly relate with food products – but raises questions about LULUCF emissions, which in principle can relate to other activities such as urbanisation. However, (IPCC, 2019[2]) estimates that the contribution of the global food system accounts for 84% of the total net LULUCF emission globally. Since times series for such a share are unavailable at the country level, the CBAFOLU indicators make the (simplifying) assumption that all LULUCF emissions relate to food products.

The sectoral coverage of the OECD ICIO framework follows the ISIC rev. 4 classification at the 2-digit level. It aggregates agriculture, forestry and fisheries activities (ISIC rev. 4 Section A). Thus, while primarily focussed on emissions from AFOLU activities, the CBAFOLU indicators also include energy-related GHG emissions from fisheries. Departing from standard terminology to simplify the discussion, any reference to AFOLU activities in this paper will also cover fisheries.

Recently, the OECD ICIO framework has been used to estimate the amount of CO_2 emissions from fuel combustion embodied in trade (Yamano and Guilhoto, 2020[6]; Wiebe and Yamano, 2016[7]). However, other gases account for the bulk of emissions from the AFOLU sector – i.e. methane (CH_4), nitrous oxide (N_2O), and indirect CO_2 emissions from land use, land-use change and forestry (LULUCF) – which are also not accounted for in this earlier work. Therefore, existing studies underrepresent AFOLU's contribution to global GHG emissions. Relying on the same methodology, the contribution of the CBAFOLU indicators fills this gap and adds CH_4, N_2O and LULUCF emissions to existing estimates of emissions embodied in global production.

Using the OECD ICIO matrix algorithm that decomposes the GVC requires the full coverage of emissions data in terms of both time and geography. That is, to construct the CBAFOLU indicators, it is first necessary to compile a dataset on AFOLU emissions that fully covers the 65 countries of the OECD ICIO system for the period 2005-15.

[5] The decomposition of the GVC has many applications. Well-known indicators relying on the OECD ICIO framework are the trade in value added (TiVA) indicators such as domestic value added as a share of exports, backward and forward linkages, foreign value added as a share of domestic final demand. See http://oe.cd/tiva.

[6] Technical details on this methodology and associated matrix computations are provided in Annex A. See also (Wiebe and Yamano, 2016[7]) and (Yamano and Guilhoto, 2020[6]).

2.2. Combining existing sources of emissions data into one consistent dataset

The approach to construct such a dataset on AFOLU emissions is based on combining the following data sources:

- The Air Emission Accounts (AEAs) undertaken by the OECD Statistics and Data Directorate
- The UN Framework Convention on Climate Change (UNFCCC) inventory reports
- The FAOSTAT emissions database.

The data robustness varies both across sources and across countries. In particular, a distinction can be made between Annex I and non-Annex I parties of the UNFCCC.

For Annex I countries of the UNFCCC,[7] the AEAs and UNFCCC inventories are datasets officially reported by countries' statistical offices. They follow the IPCC guidelines on methodologies to estimate GHG emissions, including, in some cases, the use of advanced modelling approaches that rely on detailed knowledge and specific situations of countries (Gütschow et al., 2016[8]). Therefore, they are the best available estimates of sectoral GHG emissions at the country level.

The AEAs are preferred over UNFCCC reports because the former breaks down industries according to the ISIC Rev. 4 classification, which is the same as the OECD ICIO framework. Therefore, estimates from AEAs can be directly applied to the OECD ICIO infrastructure. However, the AEAs currently cover only 32 countries and do not include emissions related to LULUCF (Flachenecker, Guidetti and Pionnier, 2018[9]). Annex I countries' UNFCCC inventories can be used directly to complement the AEAs since Annex I countries report sectoral accounts of GHG emissions to the UNFCCC every year, providing a consistent time series of emissions. The AEAs and the UNFCCC inventories are both based on comparable methodologies,[8] the main difference between the two datasets is the sectoral classification, which is reconciled through some mapping explained in the next subsection.

Non-Annex I countries do not systematically report estimates of GHG emissions to the UNFCCC. When they do, estimates are likely to be based on less advanced estimation methods that do not account for local specificities.[9] In contrast, while the FAOSTAT emissions database also relies on simplifying assumptions, it achieves universal country and time coverage of GHG emissions in agricultural and LULUCF activities. As a result, the FAOSTAT emissions database is the preferred data source for GHG emissions associated with AFOLU activities in non-Annex I countries.

2.3. Emissions coverage of the CBAFOLU indicators

The AFOLU emissions coverage of the CBAFOLU indicators is as large as the combination of existing data sources permits for consistent and complete geographical and time coverage – a requirement imposed by the use of the ICIO infrastructure that cannot accommodate missing values. However, such a requirement leads to the exclusion of some AFOLU subcategories from the CBAFOLU indicators as detailed below.

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[7] Annex I parties to the UNFCCC are Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, the European Union, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, the Russian Federation, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom, and the United States.

[8] See Flachenecker et al. (2018[9]) for a discussion.

[9] The IPCC provides guidelines for national GHG inventories that follow a tiered approach. A tier represents a level of methodological complexity with Tier 2 and Tier 3 methods being the most demanding in terms of complexity and data requirements but also providing the most accurate emissions estimates. Tier 1 methods are basic and are designed to use readily available national or international statistics in combination with the default emission factors and additional parameters provided by the IPCC, making it feasible to develop estimates for all countries (IPCC, 2006[17]).

Emissions measured in the agricultural sector

The CBAFOLU indicators cover two categories of GHG emissions in the agricultural sector: direct emissions and (indirect) emissions from energy use.

Direct emissions are mostly accounted for by CH_4 and N_2O emissions – and, to a much lesser extent, CO_2 emissions.[10] The CBAFOLU indicators cover direct emissions from the following subcategories of the agricultural sector: enteric fermentation, manure management, rice cultivation, agricultural soils, and the burning of agricultural residues. These correspond respectively to UNFCCC subcategories 3A, 3B, 3C, 3D, and 3F of category 3 “Agriculture”. Subcategory 3E “Prescribed burning of savannahs” is considered to be associated with land use and land-use change emissions.[11] CO_2 emissions associated with liming and urea application – UNFCCC subcategories 3G and 3H respectively – are not included in the CBAFOLU indicators because they are not provided by the FAOSTAT emissions database, thereby making it impossible to achieve a full country coverage. *Indirect*, energy-use, emissions in the agricultural sector largely consist of CO_2 emissions – and to a lesser extent by CH_4 and N_2O emissions – from the use of combustion engine vehicles (e.g. mobiles sources including trucks for crops harvest and planes for pesticides spreading).

Data sources for direct emissions in agriculture are the AEAs, the UNFCCC reports and the FAOSTAT emissions database combined by the approach described in the previous section. In contrast, energy-use emissions are sourced from the FAOSTAT emissions database – for CH_4 and N_2O emissions – and the IEA dataset for CO_2 emissions. This is because there exist significant conceptual inconsistencies among countries reporting agricultural energy-use emissions to the UNFCCC. For instance, some countries report these CO_2 emissions under the UNFCCC subcategory 1A3 “Transport” as they consider that agricultural equipment is a mobile source of emissions (EPA, 2019[10]). Some other countries report them under category 1A4c “Other sectors – Agriculture/forestry/fishing”. Harmonising data on energy-use emissions in the agricultural sector from the UNFCCC database is therefore too tenuous and relying on the FAOSTAT emissions database and the IEA dataset on CO_2 emissions from fuel combustion is the preferred option.

Two additional remarks are in order. First, one issue with the FAOSTAT emissions database is that it reports energy-use emissions in the agricultural sector only until 2012. The IEA dataset on CO_2 emissions is therefore a preferred source to obtain data on energy-use emissions of CO_2. Emissions of CH_4 and N_2O come from the FAOSTAT emissions database and are extrapolated for years 2013-2015.[12] Second, the AEAs numbers already include emissions from energy use. Therefore, energy-use emissions in agriculture will be added only to countries that do not report to the AEAs.

Emissions measured in land use and land-use change and forestry (LULUCF)

The CBAFOLU indicators provide emissions estimates of three LULUCF subcategories: i) forest land; ii) burning savannahs; iii) burning other biomass. Emissions from other LULUCF activities – emissions associated with carbon losses from drained histosols under cropland and grassland – are excluded because of an incomplete coverage in the data sources.[13]

On forest-land emissions, the CBAFOLU indicators cover the net CO_2 emissions (positive and negative) induced by changes in the carbon stocks of forests. Forests are ecosystems that stock CO_2 in the vegetation itself and in other reservoirs such as detritus and soil organic matter pools (Apps, 2003[11]). There is a net release (or removal) of CO_2 emissions when there is a net carbon stock loss (or gain) taking

[10] Emissions of CO_2 are generated through liming and urea application. These activities account for a small share of total direct emissions from agriculture. For instance, they accounted for 1.5% of total direct emission from agriculture in the United States in 2015 (EPA, 2019[10]).

[11] This follows an IPCC methodological recommendation to consider emissions from all fires on managed lands as associated with LULUCF activities. See (IPCC, 2006[15]) for more details.

[12] The extrapolation is made by linearly applying the average growth rate from the last two years to missing years (2013-15).

[13] The FAOSTAT provides times series of emissions for LULUCF cropland and grassland subcategories but a significant number of countries are missing. Missing data points include countries with a large agricultural sector such as Mexico, Cambodia, and the Philippines.

into account the living aboveground and belowground biomass pool, the dead organic matter and soil (FAO, 2016[12]). The most important drivers of emissions or removals of CO_2 include forest management practices and conversion from forest land to other land uses. As mentioned above, net LULUCF emissions are assumed to relate to food products. Therefore, positive or negative forest-land emissions are treated symmetrically. Positive emissions are assumed to relate to the expansion of agricultural land – e.g. through deforestation – while negative emissions are assumed to relate to the compression of agricultural land – e.g. through afforestation – made possible by productivity gains.

The CBAFOLU indicators also cover emissions from burning savannahs and burning other biomass.[14] Burning savannahs generate CH_4 and N_2O emissions from the combustion of vegetation biomass in the following land covers: savannah, woody savannah, open shrub lands, closed shrub lands, and grasslands (FAO, 2019[13]). Burning other biomass generate CH_4 and N_2O emissions from fires in the following land covers: humid tropical forest, other forest, and organic soils (FAO, 2019[14]). For the organic soils item only, CO_2 emissions are also included.

The CO_2 emissions from burning woody vegetation – i.e. savannahs, humid tropical forest, and other forest – are not included in the CBAFOLU indicators because the FAOSTAT emissions database does not report them. Whether or not CO_2 emissions from vegetation fires account for national GHG emissions is subject to debate. Burning cropland and grassland areas can be assumed to be carbon neutral because CO_2 emissions fires would be counterbalanced by CO_2 removals from subsequent re-growth of the vegetation within one year – this is the so-called synchrony assumption. This assumption is, however, disputable for forest land and savannahs because losses from fires represent several years of growth and carbon accumulation (IPCC, 2006[15]).

Emissions data from these LULUCF subcategories come from the FAOSTAT emissions database only. The approach for combining different data sources described in the previous section is not applied for the following reasons. First, the AEAs do not cover LULUCF emissions. Second, LULUCF categories in UNFCCC and FAOSTAT are not exactly equivalent. For instance, the FAOSTAT emissions database separates emissions from forest land, grassland, and burning savannahs. Within the UNFCCC framework however, some countries report emissions associated with savannah burning directly in categories 4A "Forest land" and 4C "Grassland" – see the Australian National Inventory Report 2015 as an example (Australian Government, 2017[16]). Mapping LULUCF subcategories from UNFCCC onto FAOSTAT is consequently not possible. Therefore, only the FAOSTAT emissions database – the largest dataset allowing for complete geographic coverage – is used a source for LULUCF emissions.

Finally, the CBAFOLU indicators also cover energy-use emissions in forestry activities. As for agricultural activities, the IEA dataset on CO_2 emissions is the source to obtain data on energy-use emissions of CO_2. Unlike agricultural activities however, energy-related emissions of CH_4 and N_2O are not reported by the FAOSTAT emissions database and cannot therefore be covered by the CBAFOLU indicators.

Emissions measured in fisheries

GHG emissions in fisheries are primarily accounted for by CO_2 emissions – and to a much lesser extent by CH_4 and N_2O emissions – from fuel combustion from mobile sources associated with fishing activities (i.e. fishing vessels). Following the approach used to obtain data on energy-use emissions in the agricultural sector, energy-use emissions of CO_2 are obtained from the IEA dataset on CO_2 emissions and emissions of CH_4 and N_2O come from the FAOSTAT emissions database and are extrapolated for years 2013-2015.

Summary of the CBAFOLU indicators coverage

The following table summarises the coverage of the CBAFOLU indicators by sector and by type of gas.

[14] Burning savannahs and burning biomass are two separate categories in the FAOSTAT emissions database.

Table 2.1. Coverage of gases and categories of the indicators

	CO2	CH4	N2O
Agriculture			
Direct emissions	Excluded [1]	AEAs, UNFCCC and FAOSTAT combined [2]	AEAs, UNFCCC and FAOSTAT combined [2]
Energy use	IEA CO_2 emissions on fuel combustion dataset [3]	FAOSTAT [4]	FAOSTAT [4]
Fisheries			
Energy use	IEA CO_2 emissions on fuel combustion dataset [3]	FAOSTAT [4]	FAOSTAT [4]
FOLU			
Forest land	FAOSTAT	Non-existent	Non-existent
Savannah burning	Excluded under the synchrony assumption	FAOSTAT	FAOSTAT
Burning biomass (forest)	Excluded under the synchrony assumption	FAOSTAT	FAOSTAT
Burning organic soils	FAOSTAT	FAOSTAT	FAOSTAT
Energy use	IEA CO_2 emissions on fuel combustion dataset [3]	Excluded [1]	Excluded [1]

Notes: 1. This category of emissions is unavailable from FAOSTAT but negligible in magnitude.
2. Countries reporting to the AEAs have numbers that already include emissions from energy use. Therefore, energy-use emissions in agriculture will be added to countries that do not report to the AEAs only.
3. The IEA dataset is preferred to avoid time extrapolation from FAOSTAT (for years 2013-15).
4. FAOSTAT numbers are extrapolated for years 2013-15. In addition, FAOSTAT numbers on energy-use emissions in agriculture are added to countries that do not report to the AEAs only because countries AEAs numbers already include emissions from fuel combustion.
Source: Authors' elaboration.

3. Concluding remarks

This paper presents a methodology to create preliminary indicators of consumption-based emissions from AFOLU activities (CBAFOLU). These indicators provide estimates of bilateral flows of GHG emissions from AFOLU by decomposing the global value chain. By tracing back the origins of the emissions from the country of their final consumption, the GHG emissions flows across countries can be monitored, which is a building block towards better understanding the distribution of emissions associated with AFOLU activities across the global economy. Given their preliminary nature, the CBAFOLU indicators should be considered as a first building block in a series of steps that explore the allocation of AFOLU activities across countries through the lens of sustainability.

Perhaps, the main limitation of the CBAFOLU indicators is that AFOLU activities are aggregated in one single sector. Therefore, an important next step would be to break the indicators down into AFOLU subsectors such as rice, maize, wheat, livestock, oilseeds, vegetables, fruits and nuts, among others. Such a disaggregation would make it possible to measure the extent to which changes in AFOLU emissions embodied in global production are accounted for by changes in the distribution of the production of specific goods and by changes in production methods leading to lower emissions intensities. Such an exercise requires data of a much higher quality. In particular, data should allow for a precise estimation of the relation between net (positive or negative) changes in LULUCF emissions and changes in agricultural practices leading to expansion or compression of agricultural land. A consistent cross-country dataset providing such information does not currently exist and should be a priority for countries interested in building knowledge in this policy area.

Future research with a more granular version of the CBAFOLU indicators could focus on estimating the effects of policies targeting emissions reduction in the agricultural sector. In particular, the CBAFOLU indicators can be used in combination with the OECD Trade model METRO (ModElling TRade at the OECD).[15] The economic impact of changes in policy, technology and other factors can be simulated with METRO and the associated trade effects can then be translated into changes in cross-border flows of GHG emissions estimated by the CBAFOLU indicators. Such analytical work would be helpful to assess the extent to which climate policies would efficiently redirect AFOLU activities to countries with lower carbon intensities of equivalent production – an important condition to achieve mitigation targets in AFOLU activities – while tracking offsetting adjustments.

[15] https://www.oecd.org/trade/topics/metro-trade-model/.

Annex A. Estimation of consumption-based emissions with the ICIO system

Following (Wiebe and Yamano, 2016[7]), CC_i^{rs}, the emissions associated with final demand in country s but generated upstream by industry i in country r, can be calculated by multiplying the production-based emissions factors[16] diagonal matrix $\boldsymbol{EF}$ (of size $NK \times NK$, where N is the number of countries and K the number of industries in the OECD ICIO system) with the global Leontief inverse $(\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}$ (of size $NK \times NK$) and global final demand matrix $\boldsymbol{Y}$ (of size $NK \times N$) from the OECD ICIO.

In matrix notations, this multiplication is given by:

$$
\begin{bmatrix}
CC_1^{11} & & CC_1^{1N} \\
\vdots & \cdots & \vdots \\
CC_K^{11} & & CC_K^{1N} \\
\vdots & \ddots & \vdots \\
CC_1^{N1} & & CC_1^{NN} \\
\vdots & \cdots & \vdots \\
CC_K^{N1} & & CC_K^{NN}
\end{bmatrix}
$$

$$
= \begin{bmatrix}
EF_1^1 & 0 & \cdots & 0 & \\
0 & EF_K^1 & & & \\
\vdots & & \ddots & \vdots & \\
 & 0 & \cdots & EF_1^N & 0 \\
 & & & 0 & EF_K^N
\end{bmatrix}
\begin{bmatrix}
1 - A_{11}^{11} & \cdots & -A_{1K}^{11} & & -A_{11}^{1N} & \cdots & -A_{1K}^{1N} \\
\vdots & \ddots & \vdots & \cdots & \vdots & \ddots & \vdots \\
-A_{K1}^{11} & \cdots & 1 - A_{KK}^{11} & & -A_{K1}^{1N} & \cdots & -A_{KK}^{1N} \\
 & \vdots & & \ddots & & \vdots & \\
-A_{11}^{N1} & \cdots & -A_{1K}^{N1} & & 1 - A_{11}^{NN} & \cdots & -A_{1K}^{NN} \\
\vdots & \ddots & \vdots & \cdots & \vdots & \ddots & \vdots \\
-A_{K1}^{N1} & \cdots & -A_{KK}^{N1} & & -A_{K1}^{NN} & \cdots & 1 - A_{KK}^{NN}
\end{bmatrix}^{-1}
\begin{bmatrix}
y_1^{11} & & y_1^{1N} \\
\vdots & \cdots & \vdots \\
y_K^{11} & & y_K^{1N} \\
\vdots & \ddots & \vdots \\
y_1^{N1} & & y_1^{NN} \\
\vdots & \cdots & \vdots \\
y_K^{N1} & & y_K^{NN}
\end{bmatrix}
$$

where CC_i^{rs} is the amount of emissions generated in country r by industry i for the final demand of country s, EF_i^r is the emission factor of industry i in country r, A_{ij}^{rs} is the requirement coefficient of industry i in country r for intermediate inputs in industry j of country s's production, and y_i^{rs} is the final demand of country s for goods and services produced by industry i in country r.

Because only AFOLU emissions are considered in this case, $EF_i^r = 0$ for all industries i except agriculture, forestry and fisheries activities, which correspond exactly to the section A of ISIC rev. 4 in the OECD ICIO framework. In other words, EF_{AFOLU}^r is calculated the AFOLU emissions – estimated with the methodology outlined in Section 2 – over the output of ISIC rev. 4 section A in country r. The emissions factors of all other industries are set to 0.

[16] Emissions factors, also called emissions intensities, are calculated as the emissions-to-output ratio.

Annex B. Country and sector coverages of the OECD ICIO 2018 edition

Table A B.1. Country coverage of the OECD ICIO 2018 edition

	OECD countries		Non-OECD economies
AUS	Australia	ARG	Argentina
AUT	Austria	BRA	Brazil
BEL	Belgium	BRN	Brunei Darussalam
CAN	Canada	BGR	Bulgaria
CHL	Chile	KHM	Cambodia
CZE	Czech Republic	CHN	China (People's Republic of)
DNK	Denmark	COL	Colombia
EST	Estonia	CRI	Costa Rica
FIN	Finland	HRV	Croatia
FRA	France	CYP	Cyprus
DEU	Germany	IND	India
GRC	Greece	IDN	Indonesia
HUN	Hungary	HKG	Hong Kong, China
ISL	Iceland	KAZ	Kazakhstan
IRL	Ireland	MYS	Malaysia
ISR	Israel	MLT	Malta
ITA	Italy	MAR	Morocco
JPN	Japan	PER	Peru
KOR	Korea	PHL	Philippines
LVA	Latvia	ROU	Romania
LTU	Lithuania	RUS	Russian Federation
LUX	Luxembourg	SAU	Saudi Arabia
MEX	Mexico	SGP	Singapore
NLD	Netherlands	ZAF	South Africa
NZL	New Zealand	TWN	Chinese Taipei
NOR	Norway	THA	Thailand
POL	Poland	TUN	Tunisia
PRT	Portugal	VNM	Viet Nam
SVK	Slovak Republic	ROW	Rest of the World
SVN	Slovenia	CN1	China - Activities excluding export processing
ESP	Spain	CN2	China - Export processing activities
SWE	Sweden		
CHE	Switzerland		
TUR	Turkey		
GBR	United Kingdom		
USA	United States		
MX1	Mexico - Activities excluding Global Manufacturing		
MX2	Mexico - Global Manufacturing activities		

Notes: Data are presented for 64 countries (i.e. 36 OECD countries and 28 non-OECD economies), the Rest of the World and split tables for China and Mexico. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities or third party. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.
Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".
Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.
Source: OECD Inter-Country Input-Output (ICIO) Tables (http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm).

Table A B.2. Sector coverage of the OECD ICIO 2018 edition

Code	Industry	ISIC Rev.4
D01T03	Agriculture, forestry and fishing	01, 02, 03
D05T06	Mining and extraction of energy producing products	05, 06
D07T08	Mining and quarrying of non-energy producing products	07, 08
D09	Mining support service activities	09
D10T12	Food products, beverages and tobacco	10, 11, 12
D13T15	Textiles, wearing apparel, leather and related products	13, 14, 15
D16	Wood and products of wood and cork	16
D17T18	Paper products and printing	17, 18
D19	Coke and refined petroleum products	19
D20T21	Chemicals and pharmaceutical products	20, 21
D22	Rubber and plastic products	22
D23	Other non-metallic mineral products	23
D24	Basic metals	24
D25	Fabricated metal products	25
D26	Computer, electronic and optical products	26
D27	Electrical equipment	27
D28	Machinery and equipment, nec	28
D29	Motor vehicles, trailers and semi-trailers	29
D30	Other transport equipment	30
D31T33	Other manufacturing; repair and installation of machinery and equipment	31, 32, 33
D35T39	Electricity, gas, water supply, sewerage, waste and remediation services	35,36, 37, 38, 39
D41T43	Construction	41, 42, 43
D45T47	Wholesale and retail trade; repair of motor vehicles	45, 46, 47
D49T53	Transportation and storage	49, 50, 51, 52, 53
D55T56	Accommodation and food services	55, 56
D58T60	Publishing, audio-visual and broadcasting activities	58, 59, 60
D61	Telecommunications	61
D62T63	IT and other information services	62, 63
D64T66	Financial and insurance activities	64, 65, 66
D68	Real estate activities	68
D69T82	Other business sector services	69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82
D84	Public admin. and defence; compulsory social security	84
D85	Education	85
D86T88	Human health and social work	86, 87, 88
D90T96	Arts, entertainment, recreation and other service activities	90, 91, 92, 93,94,95, 96
D97T98	Private households with employed persons	97, 98

Source: OECD Inter-Country Input-Output (ICIO) Tables (http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm).

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Comments are welcome and can be sent to tad.contact@oecd.org.