Using emissions intensity measures as a guide to national mitigation policies for agriculture and land use

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Abstract

We explore the usefulness of physical and economic measures of emissions intensity in providing guidance for greeenhouse gas (GHG) mitigation policies for agriculture and land use. Using data from nine selected countries, the ability of various measures to illuminate options for the reduction of direct and indirect emissions from agriculture is examined. At the level of individual commodities, we show that the decomposition of physical emissions ratios can provide useful insights into options for reducing direct agricultural emissions. We argue that economic measures of emissions intensity are superior to physical measures as a guide to policy. Using data for the United States we demonstrate that mitigation priority rankings can be affected by the emissions measure used. We conclude that a measure based on value added is superior to a physical emissions measure and to a measure based on the total value of output. Use of the value-added approach has a number of analytical advantages, including the ability to reflect more comprehensively the policy set available to policymakers in pursuing mitigation and other policy objectives.

Keywords: UN climate agreement; greenhouse gas mitigation; climate change; emissions intensity; policy priorities

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1. Introduction

The recent entry into force of the 2015 UN global climate agreement is an important step in addressing the challenge of global climate change. Signatories to the agreement have indicated, with varying degrees of specificity, goals for the reduction of national greenhouse gas (GHG) emissions. Many countries have included agriculture and land use in their national GHG-reduction strategies.

According to IPCC, agriculture, forestry, and other land uses (AFOLU) accounted for 24% of global GHG emissions in 2010, making AFOLU the second leading contributing sector to global emissions after electricity and heat production (25%) (Smith et al. 2014). Agriculture is the largest emitter of methane (NH_4) and nitrous oxide (N_2O). It is also a major contributor to CO_2 net emissions, particularly as sinks (e.g., forests, organic soils) are converted to agricultural activities. Agriculture's direct (non-CO_2) emissions and indirect (CO_2) emissions are accounted for under the AFOLU sector (Agriculture, Forestry, and Other land uses).

In order to reduce the overall volume of GHG emissions, countries need to identify options for mitigation in AFOLU. The balance of net emissions needs to be assessed, taking into account interlinkages between agriculture and other land uses. Possibilities for increased carbon sequestration need to be identified.

In agriculture, the achievement of global GHG reduction targets requires, at a minimum, that the emissions intensity associated with global agricultural production be reduced. Consequently, the measurement of emissions intensity and the identification of factors that contribute to it are important issues. Considerable attention has been directed towards the measurement of physical emissions intensity.

The decomposition of physical emissions ratios and changes over time can provide useful insights into mitigation challenges and options. Countries, however, face the challenge of balancing the need to limit the contribution of agriculture and land-use activities to climate change (minimizing a global negative externality), while simultaneously maintaining or enhancing the contribution of these activities to the national economy (maximizing the contribution to national income and other economic objectives, such as employment). Consequently, emissions ratios that contain economic content can also be valuable in guiding mitigation policies.

In the first two sections of the paper, we examine insights that can be gained on mitigation options, by using data from the FAO (FAOStat) on AFOLU emissions for nine selected countries/entities: Australia, Brazil, China (PRC), Ethiopia, the European Union (EU), India, Indonesia, New Zealand, and the United States (USA). Collectively these countries accounted for 48 percent of global emissions from agriculture and land use in 2008-10. Differences among these countries are indicative of the range of challenges involved in emissions reduction.

In the first section, we present data on net emissions in AFOLU for the nine countries and examine their implications for mitigation. A key issue highlighted by the analysis is the interaction between agriculture and land-use in determining net emissions and the role that changes in land use can play in achieving mitigation objectives. In the second section we focus on the measurement of direct emissions from agriculture and the derivation of indicators that highlight emissions intensity in crop and livestock production for the nine selected countries. We provide additional illustrations on what insights this approach can provide by focusing on Australia.

In the final part of the paper we present emissions ratios for 10 agricultural products in the United States to demonstrate that an emissions to value-added ratio (EVAR) provides a useful economic indicator from a mitigation policy perspective.

2. Decomposing emissions in Agriculture, Forestry and Other Land uses (AFOLU)

The production of crops and livestock generates emissions of GHGs, primarily methane (CH_4) and nitrous oxide (N_20). Emissions of CO_2 and non-CO_2 GHGs are generated from the use of soils in agriculture, but agricultural land use can also -enhance carbon sequestration. Finally, emissions and carbon sequestration can be generated through non-agricultural land uses (e.g., forestry, organic soils).

Expressed in terms of carbon dioxide equivalent (CO_2e), the composition of net emissions associated with AFOLU can be defined by equation (1). This differentiates between net direct and indirect emissions from crop and livestock production and the use of agricultural soils (NE_A), and net emissions (i.e., removals, if negative) from forests and land uses other than forestry and agriculture (NE_{FOLU}) :

$$NE_{AFOLU} = NE_A + NE_{FOLU} \tag{1}$$

Using this equation, data available from FAOStat allow us to compute an AFOLU emissions balance for the 9 selected countries/entities examined in this paper for 2008-10 (Table 1). The agricultural data include emissions from crop production through the use of synthetic fertilizers, crop residues, and the burning of crop residues; emissions attributed to livestock production from enteric fermentation, manure left on pasture, manure applied to soils, and manure management. Emissions associated with the burning of savanna and from the cultivation of organic soils are also included under the agricultural category. FAOStat does not include estimates of soil carbon sequestration in the emissions data for agriculture, although IPCC estimates that the highest mitigation potential in agriculture lies in soil carbon sequestration, affected mainly by cropland management, restoration of organic soils, and restoration of degraded soils (Smith et al. 2014).

The definition of emissions (sources only) from forests and other land uses (FOLU) in Table 1 includes the sum in CO_2e of CO_2 emissions generated by deforestation and conversion of other land uses into cropland and grassland, as well as CO_2, N_2O, and CH_4 emissions from the burning of FOLU biomass (i.e., forest and peat fires). Currently, FAOStat data under *Land Use* emissions from cropland and grassland include CO_2 emissions generated only by the conversion of organic soils to cropland and grassland use, respectively. Data on forests measure the removals, including those from afforested and reforested land, net of forest degradation (reduction in biomass carbon density). Negative CO_2 emissions (i.e., removals) denote carbon uptake and sequestration.

The decomposition in Table 1 is important for identifying the relative importance of agriculture's direct (agriculture) and indirect (other land uses) emissions for mitigation, as well as the potential associated with removals by forests.[1] In addition to the emissions balance data, the contribution of agriculture to GDP is included in the table (e.g.,) to highlight the potential economic implications of mitigation policy.

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[1] Data on national emissions by sector are available only until 2010. Data for land use sources in Australia for that period are likely to be inaccurate and in any case are non-representative of the situation since 2010. For an explanation of the FAOStat data for forest emissions and removals, see Federici et al. (2015).

Table 1. Decomposition of net emissions from AFOLU in selected countries, average 2008-2010

Averages 2008-2010	**World**	**Australia**	**Brazil**	**China**	**Ethiopia**	**EU**	**India**	**Indonesia**	**New Zealand**	**United States**
Share of Value Added Agriculture, Forestry, Fisheries in GDP	3.7%	2.3%	4.4%	10.3%	45.0%	1.4%	7.2%	13.7%	5.8%	1.0%
Emissions & removals from AFOLU sources and sinks: absolute numbers, and global shares										
Emissions from AFOLU (sources only) in GgCO2e/yr	10,715,914	339,947	1,279,795	698,515	113,942	580,818	627,785	951,812	43,821	493,890
% of AFOLU emissions in global AFOLU (sources only)	100%	3%	12%	7%	1%	5%	6%	9%	0%	5%
Net emissions (removals) from forests in GgCO2e/yr	-2,553,925	-223,394	-325,131	-397,393	-2,935	-512,748	-135,667	-606,312	-22,187	-494,267
Forest removals as % of global sinks	100%	9%	13%	16%	0%	20%	5%	24%	1%	19%
Forest removals as % of global AFOLU sources of emissions	24%	2%	3%	4%	0%	5%	1%	6%	0%	5%
Share of total national emissions (across all sectors)										
Agriculture- direct emissions	10%	14%	23%	7%	59%	8%	24%	10%	45%	5%
Land use sources (deforestation & other land uses)	12%	27%	47%	0%	20%	3%	0%	53%	7%	2%
AFOLU - sources only	22%	40%	70%	7%	80%	11%	24%	63%	52%	7%
Share of AFOLU emissions (sources only)										
Agriculture - direct emissions	47%	34%	33%	100%	74%	71%	98%	16%	86%	71%
Land use sources (deforestation and other land uses)	53%	66%	67%	0%	26%	29%	2%	84%	14%	29%
Share of agriculture's direct emissions										
due to CH_4	57%	54%	64%	49%	56%	51%	66%	51%	62%	48%
due to N_2O	43%	46%	36%	51%	44%	49%	34%	49%	38%	52%
Share of emissions from land use sources (i.e., deforestation and other land uses)										
Deforestation	66%	98%	98%	0%	33%	49%	0%	49%	52%	0%
Burning biomass (peat & forest fires)	21%	1%	2%	60%	25%	0%	20%	14%	0%	48%
Drainage of organic soils(cropland)	13%	1%	0%	35%	41%	49%	80%	36%	47%	50%
Drainage of organic soils(grassland)	0%	0%	0%	5%	1%	1%	0%	1%	1%	1%

Source: Calculated from FAOStat database

As may be seen from the table, Brazil is the largest AFOLU emitter among the countries examined, contributing 12% to global emissions from agriculture and other land use sources. Although the agriculture, forestry, and fisheries sector contributes less than 5% to national income, AFOLU emissions account for 70% of total national emissions. Taking into account removals from forests, land-use changes make a larger contribution to total emissions than direct emissions from agriculture through crop and livestock production. The main, if not the only, source of the land use emissions is deforestation. The country's main direct emissions from agriculture are methane (64%). The majority of methane emissions are associated with ruminant livestock systems (primarily through enteric fermentation). If this connection were not taken into account and mitigation efforts focused solely on reducing direct emissions from agriculture, available mitigation options would be much less effective.

Brazil is a typical case in which mitigation efforts should focus on land-sparing options in agriculture, i.e., constraining the amount of land used in agricultural production. In addition to the need to limit emissions from deforestation, Brazil's forests contribute more to global removals of carbon dioxide (13%) than the country does to global AFOLU emissions. This suggests that Brazil's largest potential to mitigate lies in enhancing its sink base and increasing global carbon removals.

Indonesia's AFOLU is another major global emitter (9% of global emissions), the main contributor to national emissions (63%), and an important sector of the economy (14% of GDP). The country was the top emitter globally from land uses (average 1990-2014), taking into account removals from forests (FAOStat data). Even more than Brazil, Indonesia's AFOLU emissions are overwhelmingly due to changes in land use (84%) rather than to agricultural production per se (16%). The latter generates roughly equal emissions from nitrous oxide (49%) and methane (51%), mostly from cultivation of organic soils and rice, respectively. However, agriculture's total impact on the country's sinks is reflected not only in the emissions generated by the cultivation of organic soils (N_2O emissions in agriculture), but also in CO_2 emissions from the induced drainage of organic soils for conversion to cropland (36% of land-use sources).

Deforestation, being the main land use source (49%), is also induced by agriculture. It is related to the establishment of palm oil plantations for use in bioenergy production, which is also a major source of national income. Fires of organic soils and tropical forests (almost 14%) are also related to the conversion of land to agricultural uses. It is also important to note that even though Indonesia's forests account for nearly a quarter of the world's pool of CO_2 removals, its annual AFOLU emissions exceed those removals.

India's AFOLU accounts for 6% of global AFOLU sources and a quarter of its national emissions. All AFOLU emissions are generated from agricultural sources (98%) and are dominated by methane (66%), mostly emitted in cattle and rice production. The largest sources of total emissions are enteric fermentation (CH_4) and manure on pasture (N_2O). Given these characteristics, it is clear that India's mitigation efforts should focus on agriculture.

The rest of the countries presented in Table 1 generate most of their emissions from agriculture. But they have significant differences, suggesting different mitigation options.

Direct emissions of agriculture in Ethiopia and New Zealand account for 59% and 45% of total national emissions, respectively. Agriculture accounts for nearly half of Ethiopia's GDP and contributes a large percentage of New Zealand's GDP, especially for a developed country. Both countries generate mostly emissions from enteric fermentation and manure left on pasture by ruminants. But that is where the similarities end.

New Zealand is an insignificant emitter at the world level, whereas Ethiopia contributes 1% of global AFOLU emissions. New Zealand's emissions are generated from agricultural production that is only marginally smaller in terms of value ($10.8 billion in 2013), compared to that in Ethiopia ($11 billion), even though Ethiopia's population is roughly twenty times larger. This reflects differences in productivity. New Zealand has a small margin for contributing to a reduction in global emissions, because it produces agricultural products efficiently, without putting a globally serious burden on land use sources of emissions. The data suggest that New Zealand's mitigation efforts should primarily focus on enhancing the country's sinks. From a global perspective, New Zealand is an efficient supplier of products (both in terms of agriculture and land use) which, from a global perspective, are high-emitting (section 3 of the paper).

Ethiopia's agriculture, on the other hand, emits substantial direct emissions from ruminant production, while20% of its national emissions result from the drainage of organic soils, deforestation, and fires. Land-sparing improvements in livestock production, such as increases in productivity, would qualify as mitigation options for Ethiopia, while raising the country's agricultural output and lowering its emissions intensity.

China, a major contributor to global AFOLU emissions (7%), contributes a large pool of removals through forests. This makes the country the second largest net sink in the world, after the United States (average 1990-2014). China's AFOLU emissions are generated almost entirely in agriculture. Moreover, China is the leading emitter of agricultural direct emissions globally (average 1990-2014). A small amount of land-use emissions comes from biomass fires and drainage of organic soils. Agricultural emissions are composed equally by methane and nitrous oxide, but methane is emitted both in ruminant and rice production. It follows that China's mitigation potential lies in agriculture and in preserving its forests and enhancing their carbon density (forest management). In agriculture, improvements in rice management will be needed.[2] While emissions reduction in ruminant production should be a focus area, the current absence of deforestation allows for reduction to be pursued either by decreasing emissions per animal or through land-sparing productivity enhancements.

The United States and the EU present great similarities relating to their AFOLU sectors. In each case, AFOLU contributes 5% to global AFOLU emissions (sources only), about 20% to the pool of global removals from forests, and accounts for less than 2% of GDP. Agriculture contributes 8% to the EU's total emissions and 5% to total US emissions. Half of the land-use emissions in the EU are generated by deforestation and the other half by drainage of organic soils for use in crop production. In the United States, for the period 2008-2010, half of the land-use emissions were due to drainage of organic soils for conversion to cropland, and the other half came from peat fires. In the EU, methane emissions (ruminant production) account for slightly more than nitrous oxide emissions (mainly from synthetic fertilizers), whereas the opposite holds in the United States. The difference is largely due to the more intensive use of organic fertilizer in the EU (animal manure applied to soils). Both the EU and the United States should focus their mitigation efforts on keeping intact or enhancing their capacity to act as the leading global sinks (e.g., through forest and other land management).

Australia's AFOLU performance is not accurately represented in the period 2008-2010, where data show a discontinuity in deforestation.[3] As of 2011, data show that Australia turned from a net source of land-use emissions to a net sink. Land use sources of emissions include the burning of non-tropical forests and the drainage of organic soils. FAOStat data also show that agriculture's direct emissions were the main source of AFOLU emissions for the period prior to 2001. In agriculture, most emissions come from the burning of savanna and from ruminant production. Fires, which are only partly associated with agricultural activities, constitute a major weakness for the country's efforts to contain emissions. While Australia should focus on forest management and fire prevention, a significant driver of future emissions will be climate change (future incidence of droughts).

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[2] Smith et al., 2007 identify a range of management practices in the production of paddy rice that can result in a reduction in emissions intensity.

[3] In all but years 2001-2010 deforestation has a zero value, which is more consistent with Australia's recent performance.

3. Decomposing direct emissions from crop and livestock production

As stated above, net emissions from agriculture include direct emissions from crop and livestock production and net emissions from the use of soil in agriculture. Equation (1) can be rewritten to distinguish between the direct and indirect components of emissions associated with agricultural activity. In equation (2), a distinction is made between emissions of methane and nitrous oxide from agriculture ($\mathrm{E_A}$) (crop and livestock production) and net emissions from the soils used in agriculture ($\mathrm{NE_S}$):

$$E_{AFOLU} = E_A + NE_S + NE_{FOLU} \tag{2}$$

We now focus on the direct emissions component ($\mathrm{E_A}$). Direct emissions from agriculture can be disaggregated into those associated with crop production ($\mathrm{E_C}$) and those attributed to livestock ($\mathrm{E_{LV}}$) (Equation 3):

$$E_A = (E_C + E_{LV}) \tag{3}$$

Focusing on the crop and livestock sub-sectors, emissions are determined by the level of output (i.e., $\mathrm{Q_C}$ and $\mathrm{Q_{LV}}$) and the emissions intensity per unit of output (i.e., $\mathrm{e_C} = \frac{\mathrm{E_C}}{\mathrm{Q_C}}$ and $\mathrm{e_{LV}} = \frac{\mathrm{E_{LV}}}{\mathrm{Q_{LV}}}$) in crop and livestock production, respectively (Equations 4 and 5):

$$E_A = [(e_C \cdot Q_C) + (e_{LV} \cdot Q_{LV})] \tag{4}$$

$$E_A = [\left(\frac{E_C}{Q_C} \cdot Q_C\right) + \left(\frac{E_{LV}}{Q_{LV}} \cdot Q_{LV}\right)] \tag{5}$$

In crop production, where the primary input is land ($\mathrm{L_C}$), emissions intensity per unit of output can be seen as the outcome of emissions per unit of land in crop production ($\frac{\mathrm{E_C}}{\mathrm{L_C}}$) and crop yields ($\frac{\mathrm{Q_C}}{\mathrm{L_C}}$). The exact relationship can be seen in the first part of equation (6) below.

In livestock production, where the main input is the stock of animals (A), emissions intensity per unit of output can be viewed as the outcome of emissions per animal ($\frac{\mathrm{E_{LV}}}{\mathrm{A}}$) and yields of animal products per head ($\frac{\mathrm{A}}{\mathrm{Q_{LV}}}$) as in the second part of Equation (6):

$$E_A = [\left(\frac{E_C}{L_C} \cdot \frac{L_C}{Q_C} \cdot Q_C\right) + \left(\frac{E_{LV}}{A} \cdot \frac{A}{Q_{LV}} \cdot Q_{LV}\right)] \tag{6}$$

Equation (6) can be further decomposed into equation (7) to show that in crop production, emissions per unit of land can be driven by emissions per unit of fertilizer ($\frac{\mathrm{E_C}}{\mathrm{F}}$) and the application rate of fertilizer ($\frac{\mathrm{F}}{\mathrm{L_C}}$). Equation (7) also shows that in livestock production systems that use grazing land (mainly ruminant systems), emissions per animal can be driven by emissions per unit of pastureland used ($\frac{\mathrm{E_{LV}}}{\mathrm{L_{LV}}}$) and the intensity with which land is used per animal ($\frac{\mathrm{L_{LV}}}{\mathrm{A}}$):

$$E_A = [\left(\frac{E_C}{F} \cdot \frac{F}{L_C} \cdot \frac{L_C}{Q_C} \cdot Q_C\right) + \left(\frac{E_{LV}}{L_{LV}} \cdot \frac{L_{LV}}{A} \cdot \frac{A}{Q_{LV}} \cdot Q_{LV}\right)] \tag{7}$$

The following can be deduced from equation 7:

In crop production, high emissions can be the result of the use of synthetic fertilizer, crop residues or residue burning (each of these are reflected in $\frac{E_C}{L_C}$ computed from FAOStat data on crop emissions[4]), as well as low crop yields. High emissions per unit of fertilizer can be due to the type of fertilizer used, application rates (emissions per unit of N fertilizer increase as N fertilizer levels increase) or to non-optimal application and poor conditions for absorbing fertilizer (e.g., limited water availability, climatic constraints, soil erosion, low soil productivity); all of these can be reflected in $\frac{E_C}{F}$. The intensity of fertilization $\left(\frac{F}{L_C}\right)$ also increases emissions per unit of land. High emissions can also be the result of high levels of output driven by high demand.

In livestock production, high emissions may be generated by high output levels or high emissions intensity. The latter may be due to high emissions per animal and low yields of livestock products. Emissions per animal may be high because of the type of animal (ruminant or non-ruminant, type of ruminant), the animal breed, feeding practices or livestock management. High emissions per animal may also be driven by grazing (manure left on pasture, poor grazing management, too high grazing density), reflected in $\frac{E_{LV}}{L_{LV}}$, or by extensive livestock systems per se (a large amount of land used per animal through grazing), reflected in $\frac{L_{LV}}{A}$. High emissions can also be the result of low animal productivity (i.e., high $\frac{\mathrm{A}}{Q_{LV}}$) due to various reasons, including type of breed, feeding practices, forage of low nutrient value, and climatic conditions.

Equation (7) facilitates the observation of an interesting aspect of ruminant production that distinguishes it from crop or non-ruminant production in mitigation approaches and relates to the use of land as an input through grazing. In contrast to intensification in crop production, where increased use of fertilizer and intensive use of soil increase emissions per unit of land, the intensification of ruminant production (i.e., through confinement and/or substitution of grazing through the provision of animal feed), reflected in lower L/A ratios could reduce emissions per animal, associated with the use of land (mainly manure left on pasture and grazing and enteric fermentation). Thus, emissions per unit of input, (E/A), are reduced directly, not only as a result of improvements in livestock management but also as a result of improved feeding, manure management, and (most important) land sparing. The latter relieves pressures on land that induce conversion of FOLU lands (emission removals/sinks) to agriculture (emission sources).

The physical decomposition of emissions by type of product provides insight into potential mitigation options for crops and livestock systems, but it is also important to consider the economic contribution of these systems. As a first approximation, we compute the ratio of emissions to the total value of output at farm level ($\frac{E}{V}$). In Table 2 we provide comparative indicators for 2014, based on the physical emissions decomposition developed above and the emissions to total value of output ratio for selected crop and livestock products in the nine countries analysed.

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[4] Note that emissions associated with the application of animal manure to cropland are counted under emissions attributed to livestock production (i.e., to the source of organic fertilizer, rather than its end use).

Table 2. Comparison of drivers of direct emissions across countries for selected products (2014)

	Australia	Brazil	China, mainland	Ethiopia	EU	India	Indonesia	New Zealand	USA
Cereals - E/Q	**0.25**	**0.18**	**0.22**	**0.10**	**0.20**	**0.30**	**0.19**	**0.20**	**0.20**
Cereals - E/L	525	816	1,218	217	1,026	675	945	1,472	1,558
Cereals - Q/L	2,100	4,573	5,449	2,323	5,715	2,401	4,954	8,026	7,620
Cereals - E/F	6.7	4.6	4.8	9.3	4.9	3.7	5.7	0.6	7.3
Cereals - F/L	78	177	253	23	211	184	165	29	214
Cereals - E/V	1.70	1.30	1.50	0.50	1.20	1.80	1.30	1.30	1.40
Rice - E/Q	**0.7**	**0.5**	**0.8**	**1.4**	**2.6**	**0.7**	**1.1**		**1.1**
Rice - E/L	7,201	2,559	5,384	3,996	21,421	3,390	5,631		9,237
Rice - Q/L	10,683	5,201	6,815	2,815	8,299	4,531	5,135		8,492
Rice - E/F	92	14	21	172	102	19	34		43
Rice - F/L	78	177	253	23	211	184	165		214
Rice - E/V	2.6	1.8	2.9	2.6	11.4	2.7	3.9		4.0
Beef - E/Q	**21.6**	**32.5**	**24.5**	**140.5**	**16.2**	**106.8**	**44.5**	**17.7**	**11.7**
Beef - E/A	2,033	1,669	1,532	1,134	1,830	717	1,532	2,012	1,683
Beef - Q/A	94	46	62.5	8	113	6.7	34.4	114	144
Beef - E/L	230	1,843	604	1,042	2,964	1,303	2,962	2,854	594
Beef - L/A	8.9	0.9	2.5	1.1	0.6	0.6	0.5	0.7	2.8
Beef - E/V	8.4	11.9	9.0	49.9	5.7	39.6	15.9	7.0	4.6
Cow's milk - E/Q	**0.6**	**1.4**	**0.7**	**5.6**	**0.6**	**1.1**	**2.3**	**0.7**	**0.4**
Cow's milk - E/A	3,306	2,093	2,095	1,644	3,690	1,674	2,479	3,188	4,437
Cow's milk - Q/A	5,688	1,526	2,979	292	6,683	1,495	1,088	4,376	10,319
Cow's milk - E/L	373	2,310	826	1,510	5,977	3,043	4,793	4,522	1,430
Cow's milk - L/A	8.9	0.9	2.5	1.1	0.6	0.6	0.5	0.7	3.2
Cow's milk - E/V	1.9	4.5	2.3	14.4	1.8	4.0	5.1	2.6	1.4
Sheepmeat - E/Q	**32**	**39**	**14**	**59**	**24**	**53**	**52**	**19**	
Sheepmeat - E/A	313	191	156	177	204	196	142	311	
Sheepmeat - Q/A	9.9	4.9	11.2	3.0	9.0	3.7	2.7	16.0	
Sheepmeat - E/L	235	1,407	764	1,086	2,204	2,378	1,832	2,940	
Sheepmeat - L/A	1.3	0.14	0.2	0.2	0.1	0.83	0.1	0.1	
Sheepmeat - E/V	12.3	14.1	5.1	18.9	8.2	19.4	17.1	7.8	
Chicken - E/Q	**0.3**	**0.3**	**0.7**	**3.4**	**0.3**	**0.6**	**3.6**	**0.2**	**0.3**
Chicken - E/A	3.9	4.2	1.8	4.0	4.0	4.0	5.0	4.0	4.0
Chicken - Q/A	13.4	13.0	2.7	1.3	13.0	7.0	1.0	16.0	11.0
Chicken - E/V	0.2	0.2	0.5	2.2	0.2	0.5	2.5	0.2	0.2
Eggs - E/Q	**0.4**	**0.9**	**0.6**	**1.6**	**0.7**	**0.5**	**1.1**	**0.4**	**0.5**
Eggs - E/A	5.4	6.0	5.4	7.2	10.0	6.0	6.0	6.0	8.0
Eggs - Q/A	15	7	9	4	14	12	6	16	16
Eggs - E/V	0.4	1.0	0.7	1.8	0.9	0.6	1.4	0.4	0.6
Pork - E/Q	**2.6**	**2.7**	**1.0**	**4.9**	**1.6**	**4.9**	**2.1**	**2.2**	**2.1**
Pork - E/A	407	226	116	276	246	173	204	360	315
Pork - Q/A	157	84	115	56	152	35	99	166	153
Pork - E/V	1.5	0.6	0.7	3.2	1.1	3.2	1.3	1.8	1.3
Notes:									
E/Q in kg CO2e per kg of product; E/L in kg CO2e per ha; Q/L in kg per ha; E/F in kg CO2e per kg of fertilizer									
F/L in kg of fertilizer per ha; E/V in kg per I$; E/A in kg per head; Q/A in kgs per head									

Source: authors' calculations based on FAOStat data

An examination of the data in Table 2 reveals interesting differences among countries in emissions intensity and how the decomposition approach provides insights into the causes of these differences. Given space limitations, just a few examples are provided:

1. For cereals, China has emissions relative to output (E/Q) that not dissimilar to those in the EU, but has much higher emissions per unit of land (E/L), due to very high application rates of fertilizer that fail to translate to higher yields. This suggests that the relative efficiency of fertilizer use in cereal production is low. This is also apparent in Ethiopia, where low emissions intensity conceals not only underutilization of fertilizer and poor application practices, but also very poor yields Fertilizer application rates in the USA are substantially higher than in the EU resulting in much higher emissions per unit of land (E/L), but the resulting high yields (Q/L) mean that emissions relative to output are the same (0.2).
2. In beef production, Ethiopia and India have the highest emissions intensity ratios, although cultural factors (importance of animals as a store of wealth in Ethiopia, and prohibitions on slaughter in India) probably have a lot to do with this. Differences in productivity are highlighted. For example, the USA has the lowest E/Q for beef reflected by high yield per animal (Q/A), despite the high ratio of pasture land per animal (L/A).
3. Ethiopia has high emissions ratios throughout its ruminant livestock production (beef, cow's milk and sheepmeat) associated with low productivity per animal. The relative inefficiency of livestock production in the country also carries through to non-ruminant production (chicken, eggs and pork).
4. The data reveal the emissions advantage of exporters of products with low emissions intensity (associated with high productivity) relative to other exporters, producing the same product with high emissions intensity. This case is illustrated by contrasting beef emissions intensity between New Zealand and Brazil, two major exporters.

The decomposition presented by equations (6) and (7) facilitates analysis of the linkage between sources of emissions (e.g., enteric fermentation, manure on pasture, etc. in livestock production and synthetic fertilizers etc. in crop production) and their drivers, and points to potential mitigation options for each country. For this purpose it is particularly relevant to compute changes in emissions ratios over time. As an example, Table 3 summarizes emissions ratios for major products in Australia for 2014 and indices obtained by comparing average values for 2012-14 to the 1999-2001 average. FAOStat includes emissions associated with the burning of savanna and the cultivation of organic soils under the heading of direct agricultural emissions, although -unlike emissions from other sources- these are not allocated to individual products.[5] The emissions associated with these two sources and their indices are also included in the table, since as noted earlier they can make a major contribution to total direct emissions attributed to agriculture.

In 2014, the largest emitting activities in Australian agriculture were the production of beef (39% of total direct emissions) and the burning of savanna, which accounted for nearly a third of direct emissions. Sheepmeat production was also a major emitting activity (16%), but with significantly reduced emissions relative to the base period. This was also the case with the burning of savanna. The activities that showed the largest increase in emissions since the beginning of the century were cereals (+17%) and chicken production (+12%).

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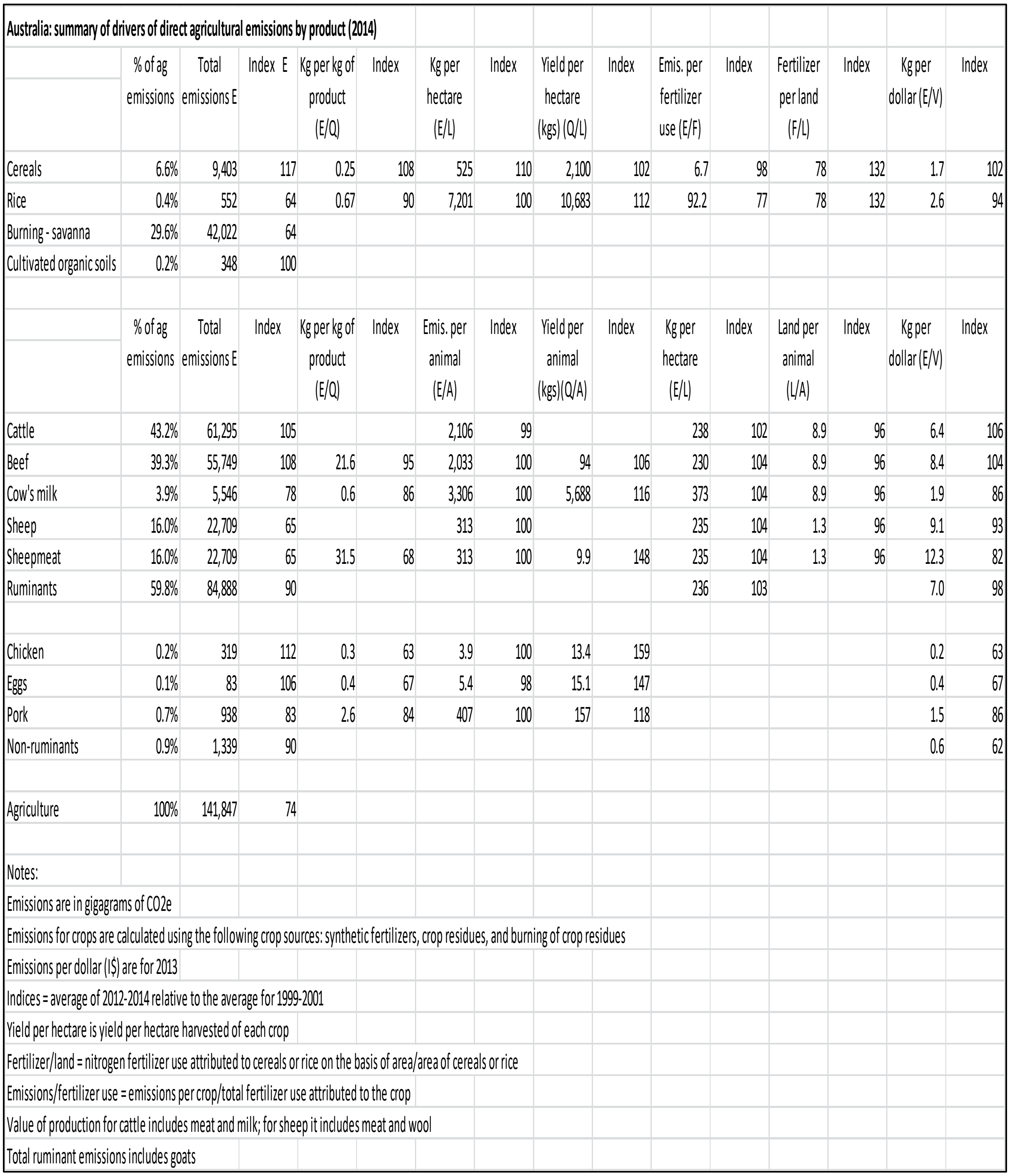
[5] These would be included in (NE_S) in equation (2).

Table 3. Australia – Drivers of direct emissions in agriculture



Australia: summary of drivers of direct agricultural emissions by product (2014)

	% of ag emissions	Total emissions E	Index E	Kg per kg of product (E/Q)	Index	Kg per hectare (E/L)	Index	Yield per hectare (kgs) (Q/L)	Index	Emis. per fertilizer use (E/F)	Index	Fertilizer per land (F/L)	Index	Kg per dollar (E/V)	Index
Cereals	6.6%	9,403	117	0.25	108	525	110	2,100	102	6.7	98	78	132	1.7	102
Rice	0.4%	552	64	0.67	90	7,201	100	10,683	112	92.2	77	78	132	2.6	94
Burning - savanna	29.6%	42,022	64												
Cultivated organic soils	0.2%	348	100												
	% of ag emissions	Total emissions E	Index	Kg per kg of product (E/Q)	Index	Emis. per animal (E/A)	Index	Yield per animal (kgs)(Q/A)	Index	Kg per hectare (E/L)	Index	Land per animal (L/A)	Index	Kg per dollar (E/V)	Index
Cattle	43.2%	61,295	105			2,106	99			238	102	8.9	96	6.4	106
Beef	39.3%	55,749	108	21.6	95	2,033	100	94	106	230	104	8.9	96	8.4	104
Cow's milk	3.9%	5,546	78	0.6	86	3,306	100	5,688	116	373	104	8.9	96	1.9	86
Sheep	16.0%	22,709	65			313	100			235	104	1.3	96	9.1	93
Sheepmeat	16.0%	22,709	65	31.5	68	313	100	9.9	148	235	104	1.3	96	12.3	82
Ruminants	59.8%	84,888	90							236	103			7.0	98
Chicken	0.2%	319	112	0.3	63	3.9	100	13.4	159					0.2	63
Eggs	0.1%	83	106	0.4	67	5.4	98	15.1	147					0.4	67
Pork	0.7%	938	83	2.6	84	407	100	157	118					1.5	86
Non-ruminants	0.9%	1,339	90											0.6	62
Agriculture	100%	141,847	74												

Notes:

Emissions are in gigagrams of CO2e

Emissions for crops are calculated using the following crop sources: synthetic fertilizers, crop residues, and burning of crop residues

Emissions per dollar (I$) are for 2013

Indices = average of 2012-2014 relative to the average for 1999-2001

Yield per hectare is yield per hectare harvested of each crop

Fertilizer/land = nitrogen fertilizer use attributed to cereals or rice on the basis of area/area of cereals or rice

Emissions/fertilizer use = emissions per crop/total fertilizer use attributed to the crop

Value of production for cattle includes meat and milk; for sheep it includes meat and wool

Total ruminant emissions includes goats

Source: authors' calculations from FAOStat data.

In beef production, the 8% increase in total emissions over the period covered was associated with an increase in production (15%). Although emissions intensity dropped (5%), this was not large enough to offset the effect of the expansion of production on emissions. Emissions intensity fell due to a 6% increase in animal yields. No changes were observed in emissions per animal (E/A index = 100), which probably indicates that emissions reduction was associated with output-increasing technological advances in beef cattle production. Emissions per unit of land increased (by 4%) in line with an increase in grazing density (decrease of L/A by 4%).

FAOStat data show that beef (non-dairy) cattle numbers expanded by 8% and that this was accompanied by a 5% expansion in pasture land. Emissions from enteric fermentation and manure on pasture increased in line with the rise in animal numbers. While emissions per unit of output declined by 5%, emissions per unit value increased by 4% due to a reduction in beef prices.

In order to examine Australia's most efficient options for mitigation from a national and a global perspective, it is useful to compare the relative emissions efficiency and drivers within and across the countries (Table 2). Australia has the fourth lowest emissions intensity in beef production (E/Q), but this is larger than that in the other developed countries. Australia's beef yield lags behind that in the USA, New Zealand, and the EU. Australia's ratio of emissions per animal is the highest among all countries examined. This ratio reflects the extensive production system, also indicated by the lowest grazing density ratio (A/L) and the lowest emissions per unit of grazing land.

It seems therefore that a mitigation option for beef production in Australia would be to increase productivity, partly through intensification, i.e., greater use of animal confinement and feed concentrates. Intensification would have land sparing effects. It would increase production costs, but would also increase yields. The relative impacts would determine whether this is a cost-effective mitigation option for Australia.

Cow's milk and sheepmeat production in Australia showed a similar trend in that total emissions declined. The decline for sheepmeat was the more dramatic (index = 65), mainly due to a large reduction in sheep numbers (index = 65), which led to an even larger savings in land (index= 62). Nevertheless, the reduction in the flock reduced production only slightly (index = 96) due to a substantial increase in productivity (Q/A) of nearly 50%. As a result, emissions intensity (E/Q) dropped by 32%. Grazing density increased and so did emissions per hectare of pastureland, leaving emissions per unit of animal unchanged at 313 kg CO_2e per head; the highest across the countries examined. Emissions per unit of grazing land are very low compared to that of other countries, and in combination with the lowest grazing density, reflects the extensive nature of the production system. The high emissions-per-animal ratio in combination with a highly extensive system also reflects forage of low nutrient content. The fall in emissions per dollar of output (index = 82) was smaller than the drop in emissions per unit of output (index = 65).[6] Both physical and value output indicators show that sheepmeat production is more emissions intensive than beef production and should rank high in national mitigation priorities.

Overall, total ruminant production in Australia has showed increases in productivity, associated with large land savings that offset the effect of the expansion in beef cattle on grazing land.[7] Land has been used more intensively (higher grazing density and emissions per unit of land), but there is no evidence of improved feeding practices that lower emissions per animal. This is an area where improvement could be made, but would raise production costs.

Chicken production, which accounts only for 0.2% of Australia's direct emissions, exhibited the second largest increase in emissions among major agricultural products. It was accompanied by nearly a doubling of the volume of output (77% increase). Emissions efficiency in the sub-sector improved more than in any other sub-sector examined (index E/Q = 63), due a 59% increase in yields. Emissions per dollar of output decreased by the same percentage (index E/V = 63) as emissions per unit of output, indicating that unit values were relatively stable. The large increase in chicken

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[6] Note that the emission ratio with respect to value for sheep, includes meat and wool.

[7] FAOStat data suggest that the total area of land used for pasture over the period examined decreased by roughly 13% over the period.

production probably reflects (as in many other countries) a shift in dietary preferences toward chicken consumption.

In comparison to other agricultural activities in Australia, chicken and cereals production are the most efficient in terms of emissions per unit of output (E/Q = 0.3). In comparison to other countries (Table 2), Australia's chicken production is competitive in emissions efficiency terms; it has the second smallest emissions per animal ratio, following China, and the second largest yield, following New Zealand. Both of these indicators suggest efficient feeding practices. When the value of production is taken into account, chicken becomes the most emissions-efficient sub-sector in Australia.

Cereals are a significant contributor to Australia's direct emissions from agriculture (6.6%). Total emissions from cereal production increased by more than any other activity (+17%), due to an increase in production (index Q = 109) that resulted mainly from an expansion in land (index L = 107) and to a lesser extent from higher yields (index Q/L = 102). Estimated emissions from fertilizer use per unit of land rose by 10% as a result of higher application rates in the expanded area under cultivation (index F/L = 132) that outstripped modest savings in emissions from more efficient application (index E/F = 98). The increase in yields that resulted from intensification was not large enough to offset the increase in emissions per unit of land, hence emissions per unit of output increased (E/Q index = 108). Cereal production was the only agricultural sub-sector in Australia that exhibited an increase in emissions intensity during the period examined. Emissions per dollar of output also increased (index E/V = 102), but by less than emissions per physical output, reflecting higher cereal prices.

Cereals is a sub-sector that appears to be relatively emissions efficient at national level, but does not compare well with the other countries in Table 2. In terms of emissions intensity per physical or value output, Australia's cereal production fared better only with respect to India. Emissions per unit of land are the second lowest among countries, reflecting the extensive nature of cereals production in Australia, but yields are the lowest. Despite a low fertilizer application rate (F/L) relative to other countries, emissions per unit of fertilizer are relatively high, possibly suggesting low nutrient absorption due to soil and climatic conditions (lack of water). These conditions seem to limit mitigation potential in cereals production in Australia possibly to the restoration of degraded soils.

Based on the above analysis, it appears that mitigation priorities in Australian agriculture should focus on intensifying ruminant production through land-sparing productivity increases, substitution of better feed for poor quality forage, and substitution in the product mix towards lower-emitting production systems. Since Australia, a major beef exporter, is more emissions-efficient than developing countries in beef production, reducing beef production in Australia would not seem appropriate from the perspective of constraining global emissions, unless international efforts were undertaken to shift diets away from the consumption of ruminant meat. .

Australia seems to have an advantage over other countries in chicken production. Despite having the fastest growth in emissions among products in the country, this is clearly a sub-sector with an emissions-efficiency advantage.

Finally, the country needs to focus on preventing fires associated with its savanna, although this will be challenging given the likelihood of increasingly adverse climatic conditions (potential increase in the incidence and severity of drought). The burning of savanna has been reduced (emissions index = 64), but there is a large variability in emissions from this source from year to year due to climatic conditions.

4. Examining direct emissions of agricultural activities relative to their economic contribution

The ratio of emissions to the value of output ($\frac{E}{V}$) used in Tables 2 and 3 provides a crude indicator of an activity's contribution to emissions relative to its economic contribution. The ratio of emissions to value added is a more accurate indicator and allows for a more comprehensive assessment of that contribution. The emissions to value-added ratio (EVAR) for a particular AFOLU activity can be defined as follows:

$$\boldsymbol{EVAR_i = \frac{(E_i - S_i)}{\sum_j P_j Q_j^i - \sum_k^i P_k\, Q_k^i}\,,\ for\ (E_i - S_i) \geq 0\ ,\ TVA^i > 0} \qquad (7)$$

where:

i = type of AFOLU activity; $i > 0$

j = product per activity i ; $j \geq 0$

k = input used in activity i; $k > 0$

E_i = total emissions from activity i (in units of CO_2e); $E_i \geq 0$

S_i = total carbon sequestration from activity i (in units of CO_2e); $S_i \geq 0$

P_j = price of output j, net of subsidies/taxes (per unit of output at farm level)

Q_j^i = quantity of output j from activity i; $Q_j^i \geq 0$

P_k = price of input k, net of subsidies/taxes (per unit of input at farm level)

Q_k^i = quantity of input k used in activity i; $Q_k^i \geq 0$

To illustrate the usefulness of EVAR, emissions intensity for ten commodities (seven crops and three livestock products) in the United States were calculated for 2014. The crops are barley, cotton, maize, rice, sorghum, soybeans, and sugar. The livestock commodities are beef, milk, and pork. Emissions estimates for the commodities were based on FAOStat data. Due to lack of data, no sequestration benefits associated with the production of these commodities were taken into account. Output values and quantities, as well as the estimates of government transfers, were obtained from the OECD's PSE/CSE database (OECD 2016. Information on value added was primarily obtained from data published by the Economic Research Service of the US Department of Agriculture. Cotton data were obtained from information published by the US Cotton Council and by university researchers of sugar beets and sugar cane production (see references).

Figure 1 summarizes the results for three emissions ratios for the ten commodities; 1. per unit of physical output (kg of CO_2e per kg of product); 2. per unit of total output value (kg of CO_2e per dollar of gross output); and 3. EVAR (kg of CO_2e per dollar of value added). The value ratios exclude transfers through government policies in the calculations (i.e., use the total value of output and the value added, net of government transfers contained in the OECD database).[8]

The results show that rankings of commodities in terms of emissions intensity vary considerably, depending on the indicator used. In terms of physical intensity, beef is by far the most emissions-intensive commodity; with respect to value added, cotton occupies this position. On the basis of emissions relative to gross output value, beef is fairly similar to cotton. Sugar appears to be a low-emissions commodity on the basis of the physical ratio, but it is actually more emissions intensive than beef, relative to value added. Low value added in cotton (after adjusting for government support)

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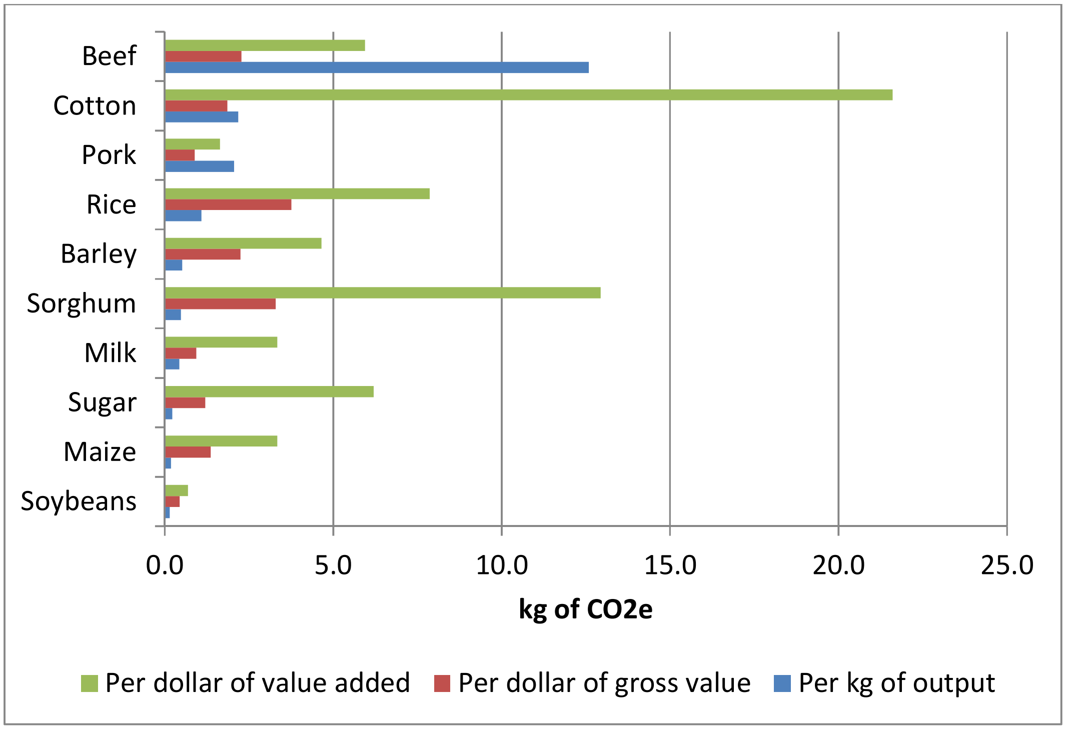
[8] The transfers excluded are those that are most directly linked to current production, i.e., the PSE support components based on commodity outputs, payments based on input use (variable input use), and payments based on current area, animal numbers, receipts or income, production required.

makes this the most emissions intensive product among those considered. This contrasts with the relatively lower emissions intensity projected in terms of physical output. Low value added in sorghum production makes it the second most emissions intensive product in terms of value added.

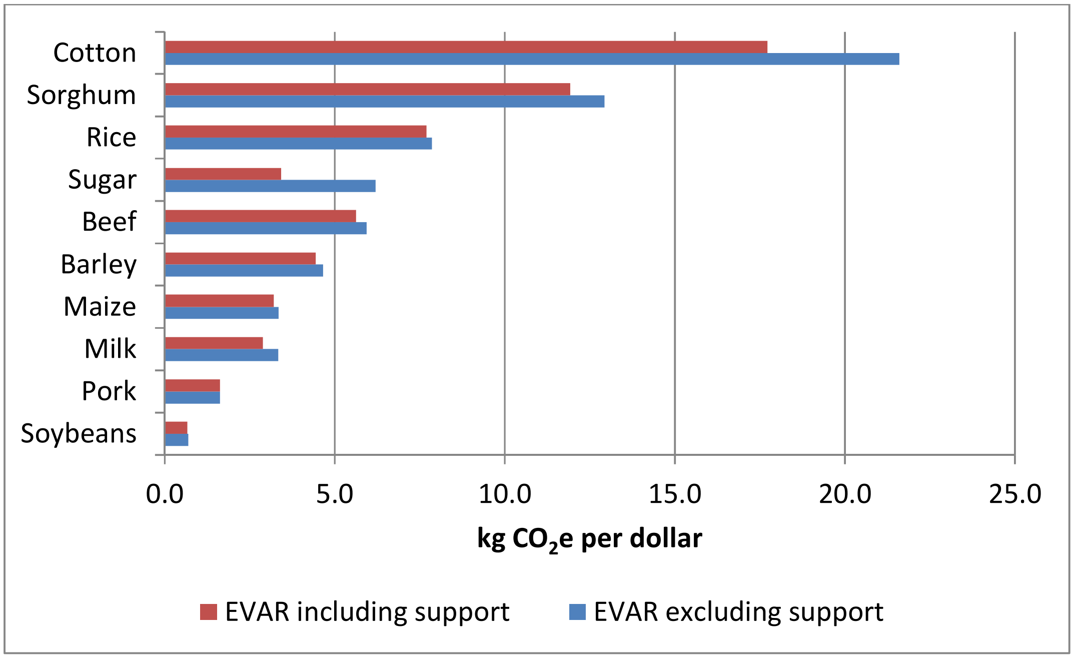
Figure 1. Comparison of emissions ratios for selected US products in 2014



Source: Based on data from FAOStat, OECD, USDA and other sources

Figure 2 provides a comparison between value-added ratios with and without adjustment for government transfers. For commodities that received the highest levels of support in 2014 -cotton (PSE = 15.2%) and sugar (PSE = 27.1%)- the impact of adjusting for government transfers (EVAR, excluding support) is particularly marked. With this adjustment, the emissions ratios for sugar and cotton increase by roughly 80% and 20%, respectively. As long as transfers do not reflect rewards to producers for supplying public goods, value-added net of government transfers is a more accurate reflection of the social value of each product, and thus the corresponding adjustment needs to be made in calculating emissions intensity indicators.

Figure 2. Emissions relative to value added, including and excluding government transfers



Source: authors' calculations based on data from FAOStat, OECD, USDA and other sources

5. Conclusions

The identification of priorities for GHG mitigation in agriculture and land use is extremely important, if countries are to meet their objectives for an overall reduction in national emissions under the UN climate change agreement. In developing countries, given the anticipated pressure on agriculture resulting from growth in demand for food and agricultural raw materials, an assessment of the relative economic contribution of different activities, and how this can be balanced against the imperative for GHG mitigation, is clearly a central issue for sustainable development.

There is a need for improved measures of emissions intensity to guide agricultural policies in both developed and developing countries. We posit that the approach developed in this paper can enable economists to provide clearer insight into the issues for policymakers.

The examination of agriculture's contribution to emissions is usually restricted to sources of direct emissions in crop and livestock production. No account is often taken of the impact of agricultural activities on the capacity of the soils used in agriculture to sequester carbon. In addition, emissions generated in other land uses are usually examined separately from the driving forces in agriculture that induced them. Consequently, the mitigation potential attributed to agriculture's supply side is grossly underestimated.

We argue that a country's mitigation potential should be first approximated by looking simultaneously at the potential to offset emissions by enhancing removals associated with agricultural soils and other land uses (e.g., forests and organic soils) and to reduce emissions from land use sources (i.e., deforestation, conversion of organic soils to cropland and grassland, and burning of non-agricultural biomass). Land use sources likely induced by agriculture should be identified and related interlinkages should be further examined. We developed a table that facilitates such a first approximation of the mitigation potential per country and across countries.

Once agriculture's role relative to other land use sources is identified, we examine the potential for reducing agriculture's direct emissions. Relying on emissions intensity comparisons alone, can be misleading, since low values could reflect low productivity rather than emissions efficiency. We propose a decomposition of emissions to elements that can be informative about the drivers of emissions and the appropriateness of mitigation options in agriculture. Comparison of the decomposed elements across countries provides useful information on the effectiveness of potential mitigation options from a global perspective.

Finally, we propose the use of an alternative emissions intensity indicator (EVAR) for guiding mitigation efforts and identifying mitigation priorities. EVAR compares the emissions generated by an economic activity to the activity's contribution to value added. In the example of the USA, mitigation priorities change radically under EVAR; beef production is seen to be less emissions-intensive than cotton and sugar. Used to account for the potential impact of distortions created by existing support policies, EVAR shows that when transfers are not taken into account, the emissions intensity for the most heavily supported products increases dramatically.

From a policy perspective, identifying mitigation priorities based on emissions per value-added allows for a more complete treatment of the policy set, including analytical separation of policies linked to output and inputs; the capacity to deal with unpriced or under-priced inputs, such as water and other positive or negative externalities associated with agriculture; the capacity to assess the relative contribution of non-agricultural land-use activities, such as forestry, to mitigation objectives. Among EVAR's advantages is that no actual or assumed price of carbon is required.

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